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DNA 3995F

VERSION 4 OF ATR (AIR TRANSPORT OF RADIATION)

Science Applications, Inc.

P.O. Box 2351

La Jolla, California 92038

January 1976

Final Report for Period 8 August 1973—30 September 1975

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Prepared for

Director

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This document serves as a guide to Version 4 of ATR (Air Transport of Radiation). This version of ATR contains a parametrization of a comprehensive transport data base for neutrons, secondary gamma rays, prompt gamma rays, x-rays and fission product radiation and provides a detailed description of weapon radiation environments in the atmosphere. This report contains pertinent parts from previous ATR reports as well as descriptions

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20.   ABSTRACT (Continued)

of the new features of the code.   Thus it is a definitive
user's guide for Version 4.

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I. INTRODUCTION

The <u>Air</u> <u>T</u>ransport of <u>R</u>adiation (ATR) code has been developed to provide a fast running computer code to predict energy-angular radiation environments from neutron, gamma-ray and X-ray sources in the atmosphere. During the development of ATR, there have been several reports[1-5] describing the capabilities of each version of the code and the generation of the data bases on which the parametrizations were based. This report summarizes the total capability of ATR-4 - perhaps the most definitive time-independent version of ATR. Detailed descriptions of the generation and parametrization of each data base component were described in the previous reports and only a brief description is provided here. Emphasis is placed, however, on the capabilities, limitations and use of the code. As such, this report may be considered as a user's manual for the ATR-4 code and except for special cases where the ATR code has been customized to a particular computer capability, this version of the code should replace all earlier versions. The time-dependent version TDATR is documented elsewhere and is treated as a separate code.

The Defense Nuclear Agency (DNA) has for some time sponsored efforts to develop sophisticated transport techniques and to accurately evaluate cross sections in order to increase the confidence in and precision of atmospheric radiation transport calculations. ATR was designed to embody the results of these efforts and make them available to the general community in a form that eliminates the need for data tables and hand folding. ATR does not perform radiation transport calculations but contains, instead, parametric representations of fluence results derived from such calculations. This approach enables

the ATR users to obtain satisfactory results without requiring either radiation transport expertise or programming sophistication. Figure 1 illustrates the characteristics of the ATR model.
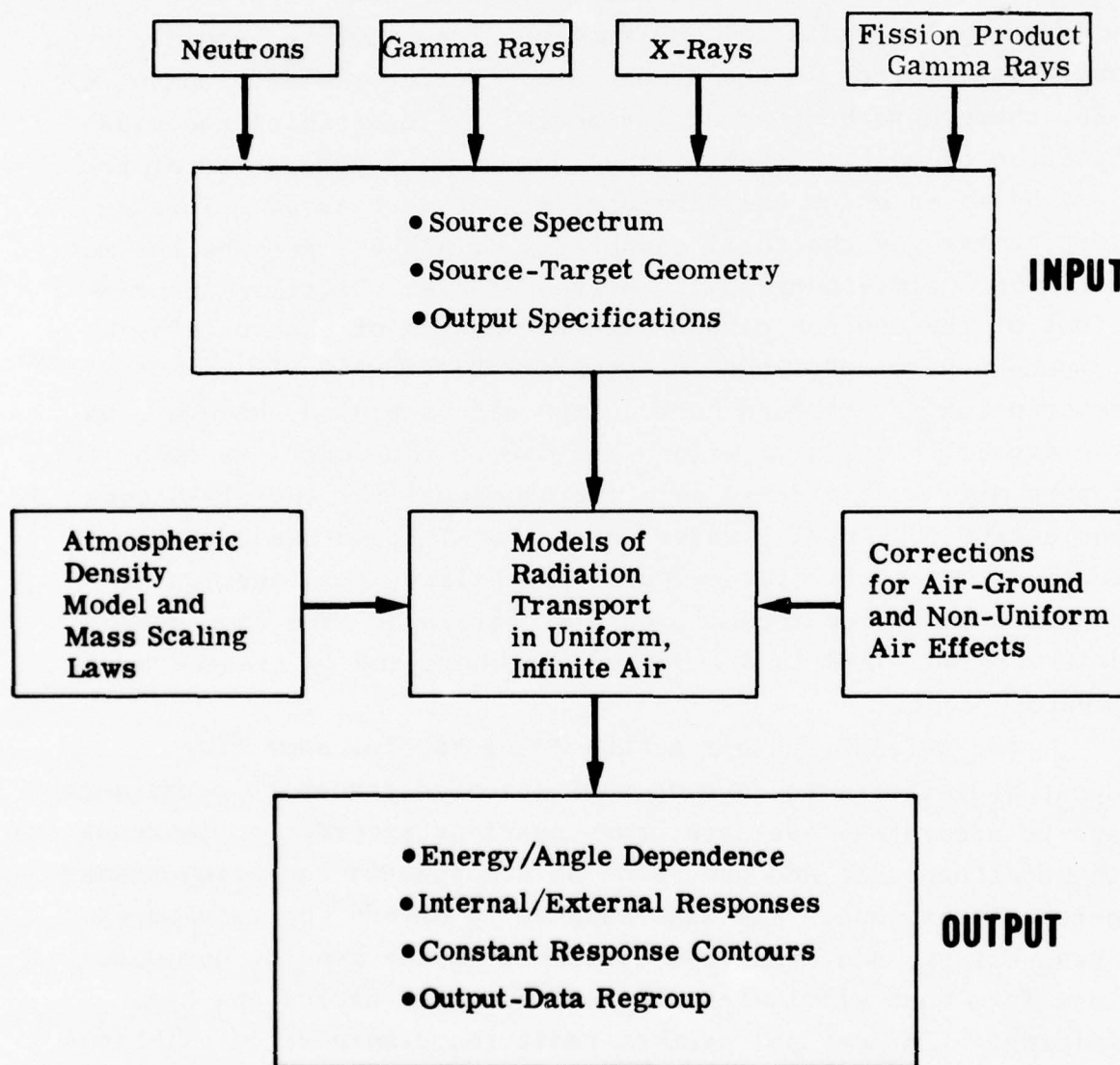
Figure 1. ATR Model

A summary of the development of the ATR code is presented in Table 1 which describes reports which have been published with a very brief description of their content. Since ATR has been an evolving code, changes in later versions have made the previous ones incomplete or obsolete. In addition, new features such as a simple fission product model have been added and are documented in this report. Thus, this report serves to document the new features in ATR-4 as well as to summarize the capabilities of the complete code package.

TABLE 1. ATR DOCUMENTATION SUMMARY

Report	Content
SAI-71-565-LJ (November 1971)	Paper given at RSIC Workshop on Radiation Transport in Air. Describes logic of code and some data base development.
DNA 2803I [1] (May 1972)	First report describing basic concepts of ATR and the first distributed version of the code--describes neutron and secondary gamma ray data base generation. Includes air-ground and exponential air correction factors.
DNA 3144Z [2] (April 1973)	Users manual for ATR-2 version of the code-- does not describe data base generation.
DNA 3279T [3] (August 1974)	Describes data base generation for photons (prompt gamma rays and X-rays) and the prompt gamma ray air-ground correction factors.
DNA 3362Z [4] (August 1974)	Summary of the capabilities of the ATR code with updates to ATR-2.
DNA-3819F [5] (July 1975)	Describes ATR-3 including new data base using DNA cross section library, new air-ground correction factors, low energy X-rays and new REGROUP routine.
DNA 4061 [6] (January 1976)	Describes TDATR, the time dependent prompt photon and secondary gamma ray version of ATR.
This report	Describes fission product model and summarizes total capability of the ATR-4 code.

2. GENERAL DESCRIPTION OF THE ATR CODE SYSTEM

The ATR code was developed to provide an easy-to-use means of determining the complete radiation environment from a nuclear weapon burst in the atmosphere. An "engineering" approach was taken in that the results of detailed calculations were parametrized to provide a compact data base instead of providing a table of results from a radiation transport code. This "engineering" approach results in a trade-off in accuracy and data storage requirements. In addition the treatment of the effect of the air-ground interface and exponential atmosphere is provided by utilizing "correction factors" rather than parametrizing many detailed transport results. Because of the lack of detailed data bases for these two effects, the "engineering" approach may be inadequate for some applications, but the philosophy of utilizing the best data available in a consistent manner has been adopted. Due to lack of data available, correction factors are only applied to integral quantities.

The ATR code is a user oriented code which can be executed in either a batch mode or from a desk teletype unit. For many problems the built-in sources and responses may be adequate, thus reducing the amount of input data that is required. Yet the flexibility to investigate a very specific case is maintained by allowing all aspects of the problem to be input. Table 2 lists the components of radiation that can be calculated by ATR. Results are provided at fixed detector locations with any source, detector or ground elevation allowed. Figure 2 shows the definition of the geometry models utilized. The

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TABLE 2.   RADIATION ENVIRONMENTS CALCULATED BY ATR

<u>Types of Radiation</u>:

        Neutrons

        Secondary Gamma Rays

        Prompt Gamma Rays

        X-rays

        Fission Product Gamma Rays

<u>Results</u>:

        Energy-angular fluence and current
        (except for fission product gamma rays)

        Angle integrated results

        Energy weighted results

mass thickness of air is determined between the source and detector and results are scaled to an equivalent distance in homogeneous air. The data base was calculated with an air density of 1.11 mg/cm^3.

The fundamental calculation in ATR is to determine the free-field fluence for a given problem geometry and source spectrum. In order to calculate such problems for the actual atmosphere, two assumptions are made:

1.   The transport of radiation between source and target can be approximated by homogeneous air transport results for a density equal to the average density between the source and target altitudes.

2.   The corrections due to air-ground interface and exponential air density effects can be included as perturbations to homogeneous air results.

~1035 g/cm^2 _____ VACUUM

Non-Uniform Air Corrections

~913 g/cm^2 _____ 15,000 Meters

Target

R_S

Source θ R_H Scaled Infinite, Uniform Air

~117 g/cm^2 _____ 1,000 Meters

H_S H_T Air-Ground Corrections

~0 g/cm^2 _____ Ground Level

Ground

SEA LEVEL
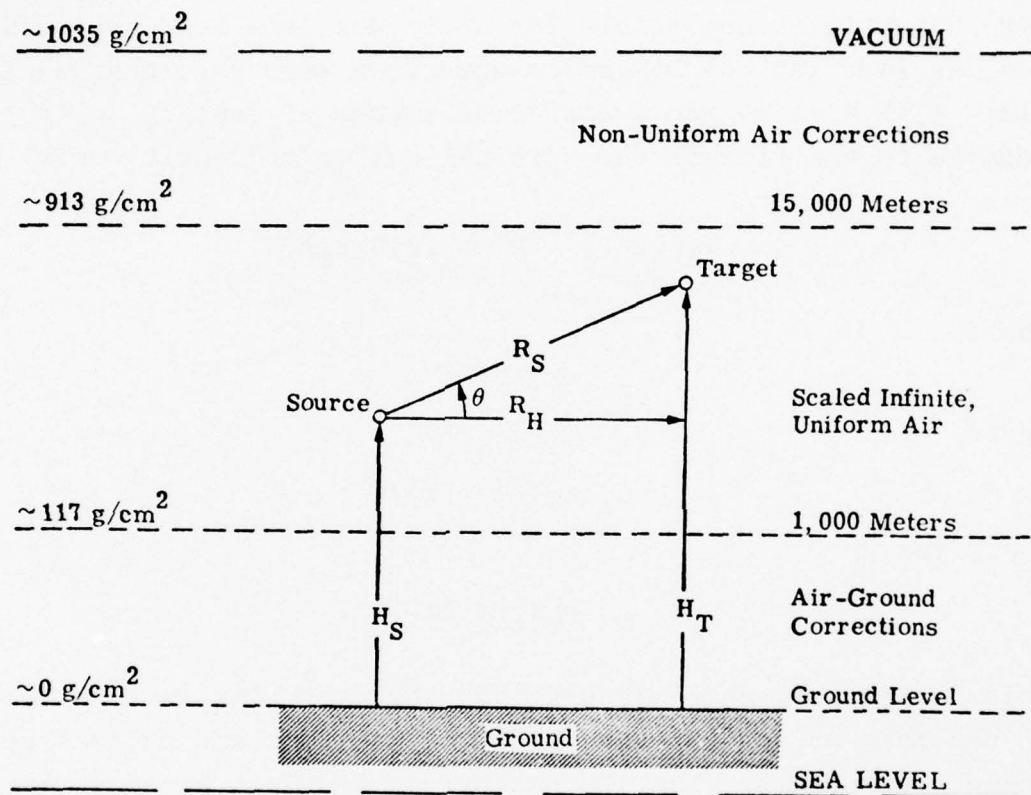
Figure 2. ATR Geometry Model

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The general calculational scheme in ATR is therefore to scale transport results from the parametric model density of 1.11 mg/cm^3 to the average density of the problem and then to include correction factors for the effects of an air-ground interface and exponential air density. These correction factors were essentially negligible for altitudes from 1-15 km. Density scaling laws for the Boltzmann equations show that the angular flux $\phi_t(E,\Omega,r)$ in the transformed system of density $\rho_t(r_t)$ is related to the flux in the original system at density $\rho(r)$ by

$$\phi(E,\Omega,r) = K^2 \phi_t(E,\Omega,r_t)$$

where

$$r_t = Kr$$

and

$$\rho_t(r_t) = \rho(r)/K$$

i.e., for

$$\rho_t r_t = \rho r \quad .$$

This is the well known result that the $4\pi r^2$ flux depends only on the mass of air through which the neutrons and photons are being transported. The ATR parametric model is based on $4\pi r^2$ quantities as a function of penetration distance in gm/cm^2 The total mass of air between source and target for a given problem is calculated from $R_s\bar{\rho}$ and used to obtain $4\pi R_s^2$ quantities from the parametric data base, i.e.,

$$4\pi R_s^2 \phi_s = 4\pi R_o^2 \phi_o \quad .$$

For

$$R_s\bar{\rho} = R_o\rho_o$$

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where

$\bar{\rho}$ = average air density of the problem

ρ_o = air density of ATR data base (1.11 mg/cm^3)

ϕ_o = radiation free-field fluence calculated by parametric equations at density ρ_o and distance R_o

ϕ_s = radiation free-field fluence of the geometry of interest.

The average air density of the problem is calculated from

$$\bar{\rho} = \frac{\int_{H_S}^{H_T} \rho(z) \, dZ}{H_T - H_S}$$

where $\rho(Z)$ is the variation in the atmospheric density as a function of altitude above sea level.

The atmospheric-density is modeled from the 1962 U.S. Standard Atmosphere for altitudes from 0-300 km based on a product of 32 exponential terms and is used for altitudes from 0-100 km. Above 100 km, an empirical curve fit is used.

The data base of ATR-4 was calculated for neutrons, secondary gamma rays, prompt gamma rays and X-rays using the ANISN[7] discrete ordinates code and utilizing the DNA cross section library[8] for all but X-rays.[23] Results as a function of source energy and range, detector energy and angle for ranges to 550 gm/cm^2 were determined. Since the earlier versions of ATR were based on neutron and secondary gamma-ray results determined with the cross sections evaluated by Straker, the new data base was produced by the parametrization of correction factors to the earlier data base. Thus it is possible to evaluate differences due to cross sections since the earlier data base was not destroyed. The fission product gamma-ray capability in ATR-4 is

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based on simple empirical models, and the basis of the radiation transport used in the fission product model comes from pervious ATR techniques. A more detailed discussion of the data bases is given in Section 3.

One of the main features of the ATR-4 code as well as previous ATR models is the use of control commands for selecting and executing options. The list of control commands for setting up an ATR run is discussed in Section 6. In general, the order of control commands is immaterial for any given set of problems. The initialization routine contains some calculations on parameters which can be evaluated on the basis of other parameters as well as some storage initialization. When a command is read in and interpreted, the corresponding subroutine is called to interpret and properly place all of the parameters corresponding to the command. Errors in control command format or structure are noted immediately but no other visible action is taken by the code until the *EXC command is used, at which point output is generated which may be just a few numbers or hundreds of pages, depending on the input parameters.

The code also contains a set of subroutines which permit an essentially format-free placement of numbers. The reading of values is upward compatible in that real values need not contain decimal points. Control commands and their associated parameter values are cumulative so that even after the results of a particular problem have been displayed, the parameter values and flags remain the same for the next problem unless specified anew with another command of the same type. Consequently, only the most essential parameters need to be specified from one problem to the next. This feature allows multiple runs to be made easily which require only a few parameter changes to be made for each problem. In order to clear out unwanted parameters the *STOP command is used after which the problem must be completely respecified.

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2.1 PARAMETRIZATION ACCURACY CONSIDERATIONS

... ig the accuracy of ATR parametrization of one dimens... ation transport, the convention is adopted that the accuracy is relative to the data base from which the fits were produced. Comparisons with other independent calculations using, say, different cross sections, energy group structure, or transport methods should first be made with the data base. In this manner, the accuracy of the parametrization can be separated from the problems associated with making comparisons of independent transport calculations. The data base used for parametrization of the neutron and secondary gamma ray transport is similar to the data reported by Straker and Gritzner.[9] The generation of the data bases for the prompt gamma rays and X-rays are described in a document by Woolson, et al.[3]

The parametrization of the data bases contains three separate fluence quantities which were independently fit. These quantities, the total fluence, the normalized scalar fluence, and the angular dependent ratio function are described in following sections. During the fitting process, accuracy standards were established for each of the fluence quantities. These standards are given in Table 3. The parametrization was based on finding techniques which would fit most of the data to the average accuracy standards given in the table. A second order correction method was then employed to improve the accuracy of the fits which exhibited anomalous errors.

The final parametrizations incorporated into the ATR code are generally accurate to within the stated standards. In particular, the total fluence functions and normalized scalar fluence were found to be generally much more accurate than the standards indicate. The ratio function fits, which contains the information about the angular variation of the fluence, were

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TABLE 3. ACCURACY STANDARDS FOR PARAMETERIZATIONS OF
INFINITE HOMOGENEOUS AIR TRANSPORT IN ATR

Fluence Type	Definition	Accuracy Standard
Total fluence	$T(E_s,R) = \iint \phi(E_s,R,E_d,\mu)\ d\mu\ dE_d$	5%
Normalized scalar fluence	$F(E_s,R,E_d) = \dfrac{\int \phi(E_s,R,E_d,\mu)\ d\mu}{T(E_s,R)}$	10%
Ratio function	$R(E_s,R,E_d,\mu) = \dfrac{\phi(E_s,R,E_d,\mu)}{T(E_s,R)\ F(E_s,R,E_d)}$	20%

compared only on the average with the data base values for prompt
gamma rays and X-rays since the angular fluence calculated by
discrete ordinates for photon transport usually exhibit non-
physical variations due to the strongly peaked angular distri-
butions. Although the scalar fluences (integrated over angle)
are accurate, the differential angular fluence required some
smoothing. Thus, the comparisons of the ratio function fits
were made with the smoothed angular fluences and not directly
with the individual data base values.

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3. ATR DATA BASES AND THEIR PARAMETRIZATION

Different components of the ATR data base have been developed over a period of about five years. The first neutron and secondary gamma ray data base utilized the cross sections assembled by Straker around 1967. This data base was used in Versions 1 and 2 of ATR and was replaced by a new data base generated with DNA cross sections evaluated around 1974. The new data base for neutrons and secondary gamma rays was first distributed in Version 3 of ATR and because of the need for comparisons with older calculations, the new data base was incorporated as a modification to the original data base.

The prompt photon data base first appeared in Version 2 of ATR with modifications to the X-ray data base to extend it to lower energies in Version 3. A delayed gamma ray (fission product) data base was added in Version 4. A separate version of ATR, TDATR, contains the time dependent prompt gamma ray and secondary gamma ray data base.

The ATR data base consists of four separate entities: a neutron and secondary gamma ray data base, a prompt gamma ray data base, an X-ray data base and a fission product data base. The first three sets of data were generated in infinite, homogeneous air at a density of 1.11 mg/cm^3 by the discrete ordinates radiation transport technique. The transport calculations were performed out to a range of 550 gm/cm^2 for neutrons, secondary gamma rays and prompt gamma rays. For the X-ray calculations the range was dependent on source energy but covered at least 15 mean-free-paths for uncollided (source) particles.

Each radiation transport data base consisted of energy and angular dependent fluence as function of range for individual source energy bands. Thus, each separate data base can be described in terms of a four-dimensional array of fluence values, defined by

$$\phi_{sikj} = \int_{E_k}^{E_{k+1}} dE \int_{\mu_j}^{\mu_{j+1}} d\mu \; \phi_s(r_i,E,\mu)/\Delta E_k \; \Delta\mu_j$$

where

ϕ_{sikj} = four-dimensional array of fluence values computed by discrete ordinates with source energy index, s; range index, i; receiver energy index, k; and angle index, j; for neutrons, secondary gamma rays, prompt gamma rays, and X-rays. The units on the fluence quantity are particles (neutron,photon)/cm²-MeV*-steradian-source "particle" in energy group s.

$\phi_s(r_i,E,\mu)$ = radiation fluence environment at range r_i, energy E and angle cosine μ in particles/cm²-MeV-steradian per unit source in energy group s.

r_i = range mesh point, in air at density 1.11 mg/cm³.

(E_k,E_{k+1}) = lower and upper limits of energy band k.

$\Delta E_k = E_{k+1} - E_k$.

(μ_j,μ_{j+1}) = lower and upper limits of angle cosine bin j.

$\Delta\mu_j = \mu_{j+1} - \mu_j$.

In the following the average value of the energy within a group denoted by $\bar{E}_n$ and defined by

---

* keV for X-rays.

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$$\overline{E}_n = \frac{E_n + E_{n+1}}{2}$$

is used. Similar relationships will be used for the angular bins. Additionally, the notation E_L, E_H will be used to indicate the lower and upper energy limits of a particular data base.

The ATR models of the radiation environment retain the group-wise features of the data base for source energy groups, receiver energy groups, and angle cosine groups but reconstruct the environment as a continuous function of r. The ATR scattered fluence model was constructed as a product of three functionals which exhibited slower variation as a function of range than the basic fluence quantity. The fluence model including the un-collided contribution is given by

$$\phi_{skj}(r) = T_s(r) \cdot F_{sk}(r) \cdot R_{skj}(r) + \frac{e^{-\sigma_s r}}{4\pi r^2} \cdot \frac{\delta_{sk}}{\Delta E_k} \cdot \frac{\delta_{jj_h}}{2\pi\Delta\mu_{j_h}}$$

where

$\phi_{skj}(r)$ = ATR fluence model at range, r, for source band s; receiver band, k; and angle cosine band, j. Units are particles/cm^2-MeV-steradian-source in group s.

$T_s(r)$ = total scattered fluence in units of particles/ cm^2 - source in group s.

$F_{sk}(r)$ = normalized scalar fluence shape in units of {fraction of $T_s(r)$ in energy group k}/MeV.

$R_{skj}(r)$ = ratio function in units of {fraction of $T_s(r) \cdot F_{sk}(r)$ in cosine bin j}/steradian.

σ_s = total macroscopic multigroup cross section for energy group s.

δ_{ik} = kronecker delta function.

j_h = forwardmost angular bin.

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In this representation, most of the spatial variation of the fluence is built into the total fluence function $T_s(r)$; the energy dependence is contained in the scalar fluence shape $F_{sk}(r)$; and the angular distribution, in the ratio function.

Several relationships exist between the real environment $\phi_s(r,E,\mu)$, and the ATR modeled fluence $\phi_{skj}(r)$. These relationships are summarized in Table 4.

TABLE 4. SCATTERED FLUENCE RELATIONSHIPS[*]

ATR Model	Radiation Environment
$\boldsymbol{\phi}_{skj}(r)$	$\displaystyle \int_{E_k}^{E_{k+1}} dE \int_{\mu_j}^{\mu_{j+1}} d\mu\,\boldsymbol{\phi}_s(r,E,\mu) \Big/ \Delta E_k\,\Delta\mu_j$
$T_s(r)$	$\displaystyle 2\pi \int_{E_L}^{E_H} dE \int_{-1}^{1} d\mu\,\boldsymbol{\phi}_s(r,E,\mu)$
$F_{sk}(r)$	$\displaystyle \frac{2\pi \int_{E_k}^{E_{k+1}} dE \int_{-1}^{1} d\mu\,\boldsymbol{\phi}_s(r,E,\mu)}{2\pi\,\Delta E_k \int_{E_L}^{E_H} dE \int_{-1}^{1} d\mu\,\boldsymbol{\phi}_s(r,E,\mu)}$
$R_{skj}(r)$	$\displaystyle \frac{\int_{\mu_j}^{\mu_{j+1}} d\mu\,\boldsymbol{\phi}_s(r,E,\mu)}{2\pi\Delta\mu_j \int_{E_k}^{E_{k+1}} dE \int_{-1}^{1} d\mu\,\boldsymbol{\phi}_s(r,E,\mu)}$

[*] Notation defined in the text, uncollided fluence not included.

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Note that with the fluence model utilized by ATR there may be several ways to construct a given fluence quantity. For example, the energy-dependent scalar fluence could be constructed from the ATR models by the operation

$$2\pi \sum_{j} \Delta\mu_j \, \phi_{skj}(r) \, ,$$

however, it can be also retrieved by

$$T_s(r) \, F_{sk}(r) + \frac{e^{-\sigma_s r}}{4\pi r^2} \cdot \frac{\delta_{sk}}{\Delta E_k} \quad .$$

The second alternative is more accurate because it does not contain possible errors present in the ratio function fit. Internally ATR employs the most accurate representation in calculating fluence quantities.

The ATR code always performs integral mass scaling to correct for density differences between the input problem geometry and the data base calculation. If necessary, corrections are made for air-ground interface or high altitude perturbations. The resulting scaled and corrected fluences, denoted by the primed quantities, are functionally related to infinite homogeneous models by

$$\phi'_{skj}(r) = f(\phi_{skj}(y), h_g, h_s, h_t)$$

where h_g is the ground height relative to sea level; h_s, h_t are the source and target heights respectively relative to the ground height; and

$$y = \frac{r}{1.11 \times 10^{-3}} \cdot \frac{1}{\lceil h_s - h_t \rceil} \int_{h_g + h_s}^{h_g + h_t} \rho(h) \, dh$$

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where $\rho(h)$ is the atmospheric density at height h above sea level. Detailed information concerning the scaling considerations can be found in Ref. 1. The ATR output quantities will now be given in terms of operations on the scaled and corrected data.

Energy-Angular Dependent Fluence

$$F_{kj}(r) = \sum_s S_s \phi'_{skj}(r) \Delta E_s \frac{particles}{cm^2 \cdot MeV \cdot steradian}$$

where

$$S_s = \text{source strength in } \frac{source}{MeV} \text{ for energy band } \Delta E_s.$$

Angular Dependent Fluence

$$F_j(r) = \sum_s \sum_k S_s \phi'_{skj}(r) \Delta E_k \Delta E_s \frac{particles}{cm^2 \cdot steradian}$$

where ΔE_k is the receiver energy band for group k.

Energy Dependent Fluence

$$F_k(r) = \sum_s S_s \left[T'_s(r) F'_{sk}(r) \Delta E_s + \frac{e^{-\sigma_s r}}{4\pi r^2} \delta_{sk} \right] \frac{particles}{cm^2 \cdot MeV}$$

Total Fluence

$$F(r) = \sum_s S_s \Delta E_s \left[T'_s(r) + \frac{e^{-\sigma_s r}}{4\pi r^2} \right] \frac{particles}{cm^2}$$

Energy-Angular Dependent Energy Fluence

$$e_{kj}(r) = \sum_s S_s \phi'_{skj}(r) \bar{E}_k \Delta E_s \frac{MeV}{cm^2 \cdot MeV \cdot steradian}$$

Angular Dependent Energy Fluence

$$e_j(r) = \sum_s \sum_k S_s \, \phi'_{skj}(r) \, \overline{E}_k \, \Delta E_k \, \Delta E_s \, \frac{MeV}{cm^2 \cdot steradian}$$

Energy Dependent Energy Fluence

$$e_k(r) = \sum_s S_s \, \overline{E}_k \left[T'_s(r) \, F'_{sk}(r) \, \Delta E_s + \frac{e^{-\sigma_s r}}{4\pi r^2} \, \delta_{sk} \right] \frac{MeV}{cm^2 \cdot MeV}$$

Total Energy Fluence

$$e(r) = \sum_s \sum_k S_s \, \overline{E}_k \, \Delta E_s \left[T'_s(r) \, F'_{sk}(r) \, \Delta E_k + \frac{e^{-\sigma_s r}}{4\pi r^2} \, \delta_{sk} \right] \frac{MeV}{cm^2}$$

Energy-Angular Dependent Number Current

$$c_{kj}(r) = \sum_s S_s \, \phi'_{skj}(r) \, \overline{\mu}_j \, \Delta E_s \, \frac{particles}{cm^2 \cdot MeV \cdot steradian}$$

where μ_j and μ_{j+1} are the cosine boundaries of cosine group j, and $\overline{\mu}_j = (\mu_j + \mu_{j+1})/2$.

Angular Dependent Number Current

$$c_j(r) = \sum_s \sum_k S_s \, \phi'_{skj}(r) \, \overline{\mu}_j \, \Delta E_k \, \Delta E_s \, \frac{particles}{cm^2 \cdot steradian}$$

Energy Dependent Number Current

$$c_k(r) = \sum_s \sum_j S_s \, \phi'_{skj}(r) \, \overline{\mu}_j \, 2\pi \, \Delta\mu_j \, \Delta E_s \, \frac{particles}{cm^2 \cdot MeV}$$

Total Number Current

$$c(r) = \sum_s \sum_j \sum_k S_s \, \phi'_{skj}(r) \, \overline{\mu}_j \, 2\pi \, \Delta\mu_j \, \Delta E_k \, \Delta E_s \, \frac{particles}{cm^2}$$

Energy-Angular Dependent Energy Current

$$e_{kj}(r) = \sum_s S_s \phi'_{skj}(r) \, \overline{E}_k \, \overline{\mu}_j \, \Delta E_s \, \frac{MeV}{cm^2 \cdot MeV \cdot steradian}$$

Angular Dependent Energy Current

$$e_j(r) = \sum_s \sum_k S_s \phi'_{skj}(r) \, \overline{E}_k \, \overline{\mu}_j \, \Delta E_k \, \Delta E_s \, \frac{MeV}{cm^2 \cdot steradian}$$

Energy Dependent Energy Current

$$e_k(r) = \sum_s \sum_j S_s \phi'_{skj}(r) \, \overline{E}_k \, \overline{\mu}_j \, 2\pi \, \Delta\mu_j \, \Delta E_s \, \frac{MeV}{cm^2 \cdot MeV}$$

Total Energy Current

$$e(r) = \sum_s \sum_j \sum_k S_s \phi'_{skj}(r) \, \overline{E}_k \, \overline{\mu}_j \, 2\pi \, \Delta\mu_j \, \Delta E_k \, \Delta E_s \, \frac{MeV}{cm^2}$$

Energy-Angular Dependent Response

$$R_{kj}(r) = \sum_s S_s \phi'_{skj}(r) \, R_k \, \Delta E_s \, \frac{response}{MeV \cdot steradian}$$

where R_k is the response function in units of response/ particles/cm^2 for energy group k.

Angular Dependent Response

$$R_j(r) = \sum_s \sum_k S_s \phi'_{skj}(r) \, R_k \, \Delta E_k \, \Delta E_s \, \frac{response}{steradian}$$

Energy Dependent Response

$$R_k(r) = \sum_s S_s R_k \left[T'_s(r) \, F'_{sk}(r) \, \Delta E_s + \frac{e^{-\sigma_s r}}{4\pi r^2} \, \delta_{sk} \right] \frac{response}{MeV}$$

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Total Response

$$R(r) = \sum_s \sum_k S_s \ R_k \ \Delta E_s \left[T'_s(r) \ F'_{sk}(r) \ \Delta E_k + \frac{e^{-\sigma_s r}}{4\pi r^2} \ \delta_{sk} \right] \text{response} \ .$$

An option exists in ATR to obtain "$4\pi r^2$" quantities. When "$4\pi r^2$" output is desired, the previous defined quantities are multiplied by the $4\pi r^2$ constant and units of cm^2 are placed in the numerator of the unit definition.

3.1 NEUTRONS AND SECONDARY GAMMA RAYS

The data base for neutrons and secondary gamma rays was generated using the DNA cross sections for nitrogen and oxygen as they existed in early 1974.

The cross section data actually used in generating the ATR data base were in the multigroup form. Briefly, multigroup cross sections are produced by expressing the angular variation of the scattering cross section as constants in a Legendre series expansion and performing weighted averages of all cross sections over the energy variable. The AMPX[10] code, which at the time was only fully operational at the Oak Ridge National Laboratory (ONRL), was used at ORNL to generate the multigroup cross sections. The same 22 neutron group and 18 photon group energy structure in previous ATR versions was used. A hand modification was made to add 10.8 MeV nitrogen capture gamma-rays to the top photon group (8-10 MeV). The cross sections used in generating the new ATR neutron and secondary gamma-ray transport data base can be obtained from ORNL, Radiation Shielding Information Center (RSIC). The radiation transport calculations were performed using the ANISN one-dimensional discrete ordinates code. The calculations were carried out in a manner similar to the previous data base calculations. Gaussian quadrature of order 16 (S_{16}) and a P_5 Legendre expansion were employed. The

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calculations were made in spherical geometry out to a range of 5 km in air, of density 1.11 mg/cm^3 and 185 radial intervals were used. A separate transport calculation was performed for a uniform source in each of the top 18 neutron energy groups.

If $\phi_S(E_s, E_d, r, \mu)$ represents the old data base for source energy group E_s, detector energy group E_d, range r and angle μ and $\phi_D(E_s, E_d, r, \mu)$ represents the new data base with the latest DNA cross sections then by integrating both quantities over angle, the following ratio function is obtained:

$$R(E_s, E_d, r) = \frac{\phi_D(E_s, E_d, r)}{\phi_S(E_s, E_d, r)} \quad .$$

Previous versions of ATR made available the approximation $\tilde{\phi}_S(E_s, E_d, r)$ to the Straker data base. Thus by parametrizing $R(E_s, E_d, r)$

$$\tilde{\phi}_D(E_s, E_d, r) = \tilde{R}(E_s, E_d, r) \, \tilde{\phi}_S(E_s, E_d, r)$$

is the representation of the new data. In actual practice, the following ratio function was parametrized:

$$R(E_s, E_d, r) = \frac{\phi_D(E_s, E_d, r)}{\tilde{\phi}_S(E_s, E_d, r)} \quad .$$

The ratio function for neutrons was relatively straightforward to curve fit by:

$$R(E_{s_0}, E_{d_0}, r) \approx \exp(a_0 + a_1 r + a_2 r^2) \quad ,$$

that is, for a given source and detector energy group the log of the ratio function is presented as a polynomial function of distance in gm/cm^2. Thus, the parametrization coefficients are functions of source and detector energy. For some sources even

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the quadratic term was not necessary. Fewer than 600 coefficients
were necessary to completely represent the neutron ratio function.

For the secondary gamma rays, the curve fitting procedure
was significantly more complicated. Each curve was examined
as a function of distance and the more complicated curves re-
quired fourth order polynomials. Furthermore, there were some
ratio functions which required a function of the following form:

$$R(E_s, E_d, r) = \exp(a_0 + a_1 r + a_2 r^2 + a_3 r^3 + \frac{a_4}{r} + a_5 \sqrt{r})$$

for adequate representation. In all, nearly 1200 coefficients
were necessary to represent the secondary gamma ray ratio func-
tions.

A final comparison was made with the data base to
make sure that the approximations did not compound in an un-
reasonable manner. The spectral comparisons show that the
maximum error of $\phi_D(E_s, E_d, r)$ versus $\tilde{\phi}_D(E_s, E_d, r)$ is on the
order of 10 percent.

After the spectral parametrization was complete, com-
parisons of the angular dependence were made and large errors
were "massaged" or corrected by simple combinations of linear
functions of distance. These massage functions were applied
to the four forwardmost angles and the averaged backward angles.
Attempts were made to keep angular errors in the parametrized
data compared to the calculations less than 20 percent, however,
larger errors may occur in isolated cases. Special attention was
given to the four forwardmost angles since they constitute most
of the importance of the angular distribution as well as behave
in a manner that lends itself to parametrization by smooth func-
tions. The averaged backward angles were not compared pointwise
directly with the data base because at some points the data base
values contained zeros or exhibited other nonphysical behavior.
The averaging scheme assures the physical trends in the data.

3.2   PROMPT GAMMA RAYS

The prompt gamma ray data base was generated in a manner similar to that for neutrons. Multigroup cross sections were processed from point data using the SMUG[10] code. DTFXRAY[11] calculations were performed for a source in each of the 18 gamma ray groups. The resulting energy-angular fluence was then processed to subtract the unscattered fluence. The scattered fluence $\phi_s(E_s, r, E, \mu)$ is a function of source energy, E_s; range r; detector energy, E; and angle cosine with respect to the source receiver ray, μ. The parametric modeling was performed with the goal of achieving accuracies in modeling the integral fluence quantities such as energy spectra without compromising the modeling of the more differential data.

The total scattered fluence function, $F(E_s, r)$, was fit with a function of the form:

$$W(\rho) = A_1 + A_2 \sqrt{\rho} + A_3 \rho + \frac{A_4}{\rho} + \frac{A_5}{\rho^2} + \frac{A_6}{\rho^3} \quad .$$

where ρ is the distance parameter in gm/cm^2 and the A_i are the constants of the parametrization.

The first step in modeling the scalar fluence was to generate a "reference shape" by fitting the spectra for a given source band at a range (several mfp's from the source) where the spectra displayed the asymptotic variation. Next, the energy fluences from each mesh point of the data base were normalized to the reference shape such that the value of juxtaposed fluences agreed at one energy normalization point, E_N.

Several different techniques were used to generate the spectral shape at a given distance. The scalar fluence function integrated over energy is normalized to unity by definition, thus only the relative variation of shape at a given distance has to be computed from the fits. The reference shapes

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for the gamma-ray sources were chosen at a distance of 3 mfp (at the source energy) and modeled with a third degree polynomial,

$$S_o(E,\rho_o) = \exp\{A_0 + A_1 \ln E + A_2(\ln E)^2 + A_3(\ln E)^3\}$$

where ρ_o is the reference distance in gm/cm^2.

A five parameter fit in distance was then made of the shape at the detector energy which corresponds to the source energy, E_s:

$$S(E_s,\rho) = \exp\{B_0 + B_1 \ln\rho + B_2(\ln\rho)^2$$

$$+ B_3(\ln\rho)^3 + B_4(\ln\rho)^{-1}\} \qquad .$$

The spectral shape for energies above the normalization energy (0.75 MeV) was computed with $S_o(E,\rho_o)$, and $S(E_s,\rho)$, by

$$S(E,\rho) = \exp\left[\ln S_o(E,\rho_o)\right.$$

$$\left. + \left(\frac{\ln E - \ln E_N}{\ln E_s - \ln E_N}\right)\left(\ln S(E_s,\rho) - \ln S_o(E_s,\rho_o)\right)\right] \quad , \quad E_N < E \leq E_s$$

The shape below E_N was assumed to be identical to the reference shape

$$S(E,\rho) = S_o(E,\rho_o) \qquad ; \qquad E \leq E_N \qquad .$$

Then the normalized scalar fluence is given by

$$S'(E,\rho) = S(E,\rho)/\int S(E,\rho) \, dE \qquad .$$

Special techniques were used for the lower source energy groups. Here, the fluence in each group was fit as a function of distance:

$$S_i(\rho) = \exp\{A_0 + A_1 \ln\rho + A_2(\ln\rho)^2 + A_3(\ln\rho)^{-1}\}$$
$$\rho < 142 \; gm/cm^2$$

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$$S_i(\rho) = \exp\left[\ln S_i(142) + \frac{\ln\rho - \ln(142)}{\ln(552) - \ln(142)}\left(\ln S_i(522) - \ln S_i(142)\right)\right]$$

$$142 < \rho < 522 \text{ gm/cm}^2$$

where $S_i(\rho)$ is the unnormalized shape for energy group i ($i \leq 4$), and the quantities $S_i(142)$ and $S_i(522)$ were saved in ATR.

Comparisons of the parametric fits of the normalized scalar fluence and the data base values indicated the fits were generally within 10% of the data base except at the .511 MeV annihilation peak. A constant factor was used to correct this anomaly.

The angle dependent ratio function is generated from the data base by the equation

$$R(E_s, r, E, \mu) = \frac{\phi(E_s, r, E, \mu)}{\int_{-1}^{1} \phi(E_s, r, E, \mu) \, d\mu} \quad .$$

The parametrization of the ratio function for photon transport was considerably more difficult than fitting the scalar fluence function. The ratio function is three dimensional for a given source energy, adding one more independent variable to the parameterization. Furthermore, several of the angular quadrature points had zero fluence values, particularly close to the source. The zero values arise from negative flux fix-up in DTFXRAY which is employed where the gradient of the fluence is so steep that extrapolation to adjacent quadrature points results in a negative fluence.

The first techniques that were tried in fitting the ratio function were unsuccessful. These attempts avoided the zero fluence problems by fitting a cumulative or integral function defined by

$$I(E_s,r,E,\mu) = \int_{\mu}^{1} \phi(E_s,r,E,\mu)\, d\mu \qquad .$$

The fluence could then be retrieved by differentiation of the integral fit. This technique appeared at first to provide a smoother function to fit across quadrature points with zero fluence values. Although the integral function could be fit with good accuracy, the functions differentiated from the fits were not of satisfactory accuracy when compared to the data base values.

The method finally employed involved grouping the sixteen angular fluence values into a set of six groups. The ratio function for each of these six angular groups was modeled with two dimensional fits in detector energy and range for each source energy. The ratio function for the sixteen angular bins was then reconstructed from the six group fits.

The ratio functions for the gamma rays were collapsed to the six groups according to the data presented in Table 5.

TABLE 5. ANGLE COSINES OF COLLAPSED ANGULAR GROUPS FOR GAMMA RAYS FROM AN ASYMMETRIC S_{16} SET

Angular Index	Angular Cosine
1	0.9983100
2	0.9808660
3	0.9558195
4	0.9245530
5	0.5174825
6	-0.7786290

The collapsing consisted of averaging the angular dependent fluence over the quadrature points in each particular group. The new data was normalized at the lowest energy according to the formulas

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$$R_i(E,\rho) = f_i(\rho) \ R_i'(E,\rho) \quad i = 1,6$$

$$R_i'(E_L,\rho) \equiv 1$$

where the source energy variable has been dropped for convenience, E_L is the lowest detector energy in the data base (0.02 MeV), and the index i refers to one of the six collapsed angular groups. The functions $R_i'(E,\rho)$ were then fit with third degree polynomials in range and detector energy by

$$R_i'(E,\rho) = \exp\{A_0(\rho) + A_1(\rho)(\ell nE) + A_2(\rho)(\ell nE)^2 + A_3(\rho)(\ell nE)^3\}$$

and

$$A_j(\rho) = \exp\{B_{j0} + B_{j1}(\ell n\rho) + B_{j2}(\ell n\rho)^2 + B_{j3}(\ell n\rho)^3\} \quad , \quad j = 0,3$$

The actual number of coefficients required was reduced by over a factor of four by combining coefficients over several groups.

The normalization factors $f_i(\rho)$ were found to be approximately constant in ρ. These factors were simply saved in an 18x6 array, one for each source and angular group.

3.3   X-RAYS

The X-ray data base was generated in the same manner as the prompt photon data base. The DTFXRAY discrete ordinates code was used to determine the X-ray fluence for a source in each of the 18 X-ray groups. The parametrization of the X-ray transport data was also performed in a manner similar to that for gamma rays. However, the reference shapes for the X-ray data base were chosen as the shape at the distance 53.8 gm/cm^2 and fit with a third order polynomial:

$$S_o(E, \rho_o) = \exp\{A_0 + A_1 \ln E + A_2 (\ln E)^2 + A_3 (\ln E)^3\} \quad .$$

A fit of the fluence in the fourth group (25-30 keV) was made as a function of range

$$S(E_4, \rho) = \exp\{B_0 + B_1 \ln\rho + B_2 (\ln\rho)^2\}$$

where $E_4 = 27.5$ keV and for all energies below E_N (50 keV) the spectral shape was computed by

$$S(E, \rho) = \exp\{\ln S_o(E, \rho_o) + (\ln S(E_4, \rho)$$

$$- \ln S(E_4, \rho_o))\} \qquad E < E_N \quad .$$

Several specialized corrections were made to shapes just below E_N to increase the accuracy of the models.

For energies above E_N, a difference function was formed from the data defined by

$$D(E, \rho) = \frac{\ln S_o(E, \rho_o) - \ln S(E, \rho)}{\ln S_o(E_s, \rho_o) - \ln S(E_s, \rho)} \quad .$$

This function was fit both in energy and range

$$D(E, \rho) = A_0(\rho) + A_1(\rho) \ln E + A_2(\rho)(\ln E)^2 + A_3(\rho)(\ln E)^3$$

where

$$A_i(\rho) = B_{i0} + B_{i1} \ln\rho + B_{i2}(\ln\rho)^2 + B_{i3}(\ln\rho)^3$$

$$+ B_{i4}(\ln\rho)^{-1} \qquad , \qquad 0 \le i \le 3 \quad .$$

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Finally, for energies above E_N the shape was computed by

$$S(E,\rho) = \exp\left[\ln S_o(E,\rho_o) - D(E,\rho) \cdot \{\ln S_o(E_s,\rho_o) - \ln S(E_s,\rho)\}\right] \quad , \quad E > E_N$$

where the shape at the detector energy corresponding to the source energy was fit in range

$$S(E_s,\rho) = \exp\{C_0 + C_1\rho + C_2\rho^2 + C_3\rho^3 + C_4\rho^{-1}\}$$

with five parameters.

Similar to the gamma ray models, special techniques were used for lower source groups. For the third and fourth source group, each non-zero fluence group was fit in range. The second source group was fit in range with a fifth order polynomial.

The normalized scalar fluence function for the X-ray sources was calculated by normalizing to unity the spectral shape computed using the techniques discussed above.

The angular data are treated similarly to the gamma rays. The data are grouped with the X-ray data base being collapsed into the six groups according to Table 6. The four most forward

TABLE 6.   ANGLE COSINES OF COLLAPSED ANGULAR GROUPS FOR X-RAYS FROM A SYMMETRIC S_{16} SET

Angular Index	Angular Cosine
1	0.98940
2	0.94460
3	0.86560
4	0.75540
5	0.36980
6	-0.75540

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angles were each allocated one group. Again, the functions were normalized at the lowest energy, E_L, by the equations

$$R_i(E,\rho) = f_i(\rho) \; R_i'(E,\rho) \quad i = 1,6$$

$$R_i'(E_L,\rho) \equiv 1 \qquad\qquad i = 1,6$$

and the $R_i'(E,\rho)$ functions were modeled.

A 4x6 array consisting of the R_i' for the highest four energy groups (including the source group) and the six angle groups was saved at two ranges. The value of R' for any range for the highest four energy groups and six angular groups was found by linear interpolation between the two ranges. For any energy group below the four highest in energy, R_i' is found by linear interpolation in energy between the fourth from the highest energy group and the value at the lowest energy which is required to be unity by the normalization.

The six angular fluence values are computed for both the gamma and X-rays by the following relationship

$$\phi_i(E_s,\rho,E) = F(E_s,\rho) \cdot S(E_s,\rho,E) \cdot R_i'(E,\rho) \cdot f_i(\rho) \, , \; i = 1,6 \; .$$

A straightforward interpolation scheme as a function of angle cosine is then used to obtain the 17 angular values of $\phi_i(E_s,\rho,E)$. The original data base had a low energy cutoff of 10 keV, but for some high altitude applications the lower energy fluence can be important. The decision to employ a 10-keV cutoff in the earlier versions was based largely on the results of Banks and Coleman.[12] Their calculations indicate that energy fluence from photons below 10 keV drops at least five orders of

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magnitude in about 2 gm/cm^2 of air--about 10 meters at sea level but 2 km at 40 km altitude. The extension of the photon data base below 10 keV was performed by treating the _uncollided_ component only. Table 7 gives the group structure and cross sections used internally to determine the uncollided fluence. The 18 fine groups are collapsed to two groups (.1-1. and 1.-10 keV) for output.

TABLE 7.   LOW ENERGY X-RAY TOTAL CROSS SECTIONS

Group	Energy Boundaries (keV)	Cross Section (cm^{-1})
1	0.1 - 0.2	24.3608
2	0.2 - 0.3	7.29217
3	0.3 - 0.4	3.44374
4	0.4 - 0.5	6.39955
5	0.5 - 0.6	15.5199
6	0.6 - 0.7	11.9949
7	0.7 - 0.8	8.35611
8	0.8 - 0.9	6.07217
9	0.9 - 1.0	4.60307
10	1.0 - 2.0	1.54431
11	2.0 - 3.0	0.325121
12	3.0 - 4.0	0.124977
13	4.0 - 5.0	6.23239(-2)[*]
14	5.0 - 6.0	3.40691(-2)
15	6.0 - 7.0	2.18828(-2)
16	7.0 - 8.0	1.42225(-2)
17	8.0 - 9.0	9.54224(-3)
18	9.0 - 10.0	6.8529(-3)

[*] Read as 6.23239×10^{-2}.

That is, the 18 fine group structure is used internally in ATR, however, only two summary groups appear in the output. The two groups represent the accumulation of results for those energy limits. Thus, if $\phi_i(r)$ represent the output of the response (fluence or dose) in the first two groups and $\phi_j(r)$ stands for the internal representation of the fine group structure, then the following relationships hold:

$$\phi_j(r) = S_j \; \mathcal{D}_j \; e^{-\sigma_j r}$$

$$\phi_i(r) = \sum_{j=j_1}^{j_2} \phi_j(r)$$

where

r = the slant range

S_j = the source spectrum values

$\mathcal{D}_j$ = the dose weights (Table 18) or other fluence weights as applicable

σ_j = the cross section values listed in Table 7

i = 1 or 2

j = an index into the fine group structure

j_1 = 1 and j_2 = 9 when i = 1

j_1 = 10 and j_2 = 18 when i = 2

Section 6.1 deals with the X-ray source specification.

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3.4 FISSION PRODUCT GAMMA RAYS

The fission product gamma ray data base consists of empirical equations which describe the growth of the debris cloud, the rise of the debris, the mass thickness of air between the debris and the detector, and the transport of the photons through the disturbed atmosphere.

The air transport data for the fission product model was generated by Version 3 of ATR. The source values given in Table 14 are the result of integrating the time dependent source distribution of Engle and Fisher[13] over all time and regrouping the results into the ATR energy group structure.

The following four dose responses

- Henderson Tissue
- Concrete Kerma
- Air Kerma
- Silicon Kerma

were calculated using the dose response function values of Table 16. These dose values were calculated at several points of slant range as a function of rho-R (i.e. units of gm/cm^2) to a maximum distance of 300 gm/cm^2 for an air density of 1.11×10^{-3} gm/cm^3. The dose values were then fit by the following six parameter equation:

$$f(r) = 4\pi R^2 D_i(r) = \exp\left(a_0 + a_1 \sqrt{r} + a_2 r + \frac{a_3}{r} + \frac{a_4}{r^2} + \frac{a_5}{r^3}\right)$$

where $D_i(r)$ represents one of the four dose responses as a function of r in units of gm/cm^2, R in cm and the a_i are the parameterization coefficients. Thus, 24 coefficients give an excellent representation of the transport data for the four dose responses. In fact, the relative error is on the order of a percent.

The source strength of fission product gamma rays is given by:

$$S(T) = 1.45 \times 10^{23} \, FYG(T)$$

at time T after fission; where it is assumed that there are 1.45×10^{23} fissions/KT, a fission fraction F, a total yield Y in KT and a time dependent fission product gamma emission rate of $G(T)$ photons/sec/fission. The decay rate $G(T)$ is given by

$$G(T) = \frac{.8}{1+.87T} \text{ photons/sec/fission}$$

which is obtained by a fit to the Engle and Fisher data. Note that the number of fissions/KT is included as a multiplier, and thus the number of "particles" generated/KT must be included as a normalization factor for neutrons and gamma rays if they are to be compared with the fission product results.

Thus the total dose is:

$$D_i(T,r) = \frac{1.16 \times 10^{23} \, FYf(r)}{4\pi R^2(1+.87T)} \quad .$$

It should be noted that r and R are related to each other for a particular geometry configuration. R is the line-of-sight distance measured in cm and r is the mass thickness of air in that same distance measured in gm/cm^2. For a fixed R, r can change due to the shock wave.

Further modifications such as air-ground interface effects, cloud rise and hydrodynamic effects are applied. The air-ground interface correction factors utilized in the fission product data base are from a modified first-last collision model. Table 8 presents a summary of air-ground functions which are used in

TABLE 8. AIR-OVER-GROUND CORRECTION FUNCTIONS
FOR FISSION PRODUCT GAMMA RAYS

Mean Free Path	$C(H_S)$	$C(H_T)$
0.00	0.834	0.875
0.01	0.843	0.882
0.02	0.847	0.887
0.05	0.855	0.897
0.10	0.867	0.910
0.25	0.893	0.935
0.50	0.921	0.959
0.75	0.943	0.973
1.00	0.961	0.981
1.50	0.983	0.991
2.00	0.992	0.995
3.00	1.000	1.000

the following manner. If H_S is the source height and H_T the target height (both measured relative to the ground), then the dose at slant range r^* is corrected by the following factors:

$$D_i'(r) = D_i(r) \; C(H_S) \; C(H_T)$$

where $C(H_S)$ and $C(H_T)$ are obtained from the values in Table 8 by interpolation. H_S and H_T are converted to a corresponding number of mean-free-paths by assuming an average energy of 1.3 MeV for the fission product gamma rays.

The cloud rise effects are inherently time dependent, therefore, R becomes time dependent: R(T) and its formulation comes from the fitted equation for the cloud height H_C measured from the burst point as a function of time T:[14]

$$H_C(T) = 61 \; Y^{.19} \; T^{.82} \text{ meters}$$

_____

* r is mass thickness.

where Y is the weapon yield in KT. If R_H is the horizontal range between the source and detector , then the following equation holds for $R(T)$:

$$R(T) = \sqrt{R_H^2 + \{H_C(T) + H_S - H_T\}^2}$$

and

$$r(T) = R(T)\ \bar{\rho}$$

where $\bar{\rho}$ is the average density in gm/cm^3 of air between H_S and H_T. The fireball rise model is independent of height of burst and thus may differ from other more detailed models such as that in the IDEA[15] code.

A modification to the mass thickness $r(T)$ is made to account for the hydrodynamic effect which creates a perturbation of the air mass. The following expression gives the scaled distance, J:

$$J = 3.473 \times 10^4 \left(\frac{QY}{P}\right)^{1/3} \text{ meters}$$

where Y is the yield in KT as before, P is the air pressure in dynes/cm^2 at the source altitude and Q is given by the following relationship:

$$Q = 1 \quad \text{if} \quad H_S > 2R_{FB}$$

$$Q = 1 + .6 \left(1 - \frac{H_S}{2R_{FB}}\right) \quad \text{if} \quad H_S \leq 2R_{FB}$$

where H_S is the source height above the ground and R_{FB} is the radius of the fireball.

Given the yield Y in KT and letting R_D represent the ratio of air density at the burst point to the density at sea level, the following expressions are used to determine the fireball radius:

$$R_A = .033 \frac{Y^{1/3}}{R_D^{1/4}}$$

$$R_G = 20 \ \ell n(1 + .05R_A)$$

$$R_O = \frac{R_A}{2}\left(\frac{R_A}{R_G} + \frac{R_G}{R_A}\right)$$

$$R_{FB} = 1000\left[3R_O + .1 \ R_O(27.5 \ R_O^{.9} - 5 \ R_O)\right] \text{(meters)} \quad .$$

The fireball radius is also used to control a validity indicator on the output, that is, an asterisk will appear on the dose output corresponding to distances that are less than two fireball radii away from the source.

A scaled unitless time is calculated from the scaled distance by:

$$L = .011831 \ (P/\rho)^{1/2} \ \frac{T}{J}$$

where ρ is the air density at the source altitude.

On the basis of J and L there are two other quantities which are calculated:[14]

If $L < 6.55$ then

$$C = J \ .55974 \ L^{.31278} + .951 \ L^{1.00025} \quad \text{and}$$

$$V = .95134 + .17505 \ L^{-.68722} \quad .$$

If $L \geq 6.55$ then

$$C = J(L + .67279) \quad \text{and}$$

$$V = 1.0 \quad .$$

A parameter X is obtained from V:

$$X = \frac{105(V^2 - 1)}{7V^2 + 35} \quad .$$

Finally, the modified mass thickness, $r'(T)$ is given by

$$r'(T) = r(T) \left[\frac{21V^2}{56V^2 - 35} \left(\frac{R_S}{C}\right)^X \right] \quad \text{for} \quad R_S < C$$

$$r'(T) = r(T) \left[1 - \left(\frac{35(V^2-1)}{56V^2 - 35}\right) \left(\frac{C}{R_S}\right) \right] \quad \text{for} \quad R_S \geq C$$

where R_S is the original slant range between the source and detector.

The final equation for the time dependent dose including the cloud rise and hydrodynamic effect is given by:

$$D_i(T,r) = \frac{1.16 \times 10^{23} \, F \, Y \, f\left[r'(t)\right]}{4\pi R(T)^2 (1 + .87T)}$$

This must be integrated over time in order to obtain the fission product gamma ray dose:

$$D_i(r) = \frac{1.16 \times 10^{23} \, FY}{4\pi} \int_0^{T_o} \frac{f\left[r'(T)\right] dT}{R(T)^2 (1 + .87T)}$$

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T_o is chosen to be 60 seconds and the integration is performed by a 12-point gauss quadrature in each of three regions:

1. 0 - 1 seconds
2. 1 - 10 seconds
3. 10 - 60 seconds

The air-ground interface correction factors are administered for each term of the integral since the configuration of the source height is time dependent.

4. BUILT-IN SOURCES, RESPONSE FUNCTIONS
AND ANGULAR QUADRATURE

Although ATR has the flexibility to utilize any neutron, gamma ray or X-ray source or any response function, it is convenient to have "standard" sources and responses that can be used with a minimum of input. All built-in sources and response functions are in the 22 neutron and 18 gamma ray group structure given in Tables 9-11. Note that the neutron source energy range is narrower than the response energy range. It is also noted that the neutron group structure starts at the lowest energy group with the highest energy - 15 MeV - being the upper boundary of the last group. Similarly, the photon groups increase with energy. Table 12 contains the group structure for X-rays.

Two neutron source spectra are built-in. A weaponized fission source and a typical thermonuclear source are contained in ATR-4. The built-in values are given in Table 13. The prompt and delayed gamma ray sources are given in Table 14. There is no built-in X-ray source spectrum although a black body spectrum may be easily specified.

Many common response functions are built-in. Tables 15-17 give the response functions for neutrons, gamma rays and X-rays. As noted in Section 3, a low energy (<10 keV) X-ray fluence is calculated internally. The response functions used in this energy range are given in Table 18. For specific problems, other response functions may be utilized, see Section 6.4.

All sources and response functions are isotropic but an energy-angular dependent response may be used by performing the integration with the energy-angular fluence external to the ATR code. The angular quadrature weight and angular intervals are given in Table 19.

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TABLE 9. SOURCE ENERGY BOUNDARIES FOR NEUTRONS (MeV)

1.	1.07(-5)* - 2.9(-5)	10.	2.35 - 2.46
2.	2.9(-5) - 1.01(-4)	11.	2.46 - 3.01
3.	1.01(-4) - 5.83(-4)	12.	3.01 - 4.07
4.	5.83(-4) - 3.35(-3)	13.	4.07 - 4.97
5.	3.35(-3) - 0.111	14.	4.97 - 6.36
6.	0.111 - 0.55	15.	6.36 - 8.19
7.	0.55 - 1.11	16.	8.19 - 10.0
8.	1.11 - 1.83	17.	10.0 - 12.2
9.	1.83 - 2.35	18.	12.2 - 15.0

TABLE 10. DETECTOR ENERGY BOUNDARIES FOR NEUTRONS (MeV)

1.	0 - 4.14(-7)	12.	1.11 - 1.83
2.	4.14(-7) - 1.12(-6)	13.	1.83 - 2.35
3.	1.12(-6) - 3.06(-6)	14.	2.35 - 2.46
4.	3.06(-6) - 1.07(-5)	15.	2.46 - 3.01
5.	1.07(-5) - 2.9(-5)	16.	3.01 - 4.07
6.	2.9(-5) - 1.01(-4)	17.	4.07 - 4.97
7.	1.01(-4) - 5.83(-4)	18.	4.97 - 6.36
8.	5.83(-4) - 3.35(-3)	19.	6.36 - 8.19
9.	3.35(-3) - 0.111	20.	8.19 - 10.0
10.	0.111 - 0.55	21.	10.0 - 12.2
11.	0.55 - 1.11	22.	12.2 - 15.0

*Numbers in parentheses denote factors of powers of ten.

TABLE 11. SOURCE AND DETECTOR ENERGY BOUNDARIES FOR
          PROMPT GAMMA RAYS, AND DETECTOR ENERGY
          BOUNDARIES FOR SECONDARY GAMMA RAYS (MeV)

1.	0.02 - 0.05	10.	1.33 - 1.66
2.	0.05 - 0.1	11.	1.66 - 2.0
3.	0.1 - 0.2	12.	2.0 - 2.5
4.	0.2 - 0.3	13.	2.5 - 3.0
5.	0.3 - 0.4	14.	3.0 - 4.0
6.	0.4 - 0.6	15.	4.0 - 5.0
7.	0.6 - 0.8	16.	5.0 - 6.5
8.	0.8 - 1.0	17.	6.5 - 8.0
9.	1.0 - 1.33	18.	8.0 - 10.0

TABLE 12. SOURCE AND DETECTOR ENERGY BOUNDARIES FOR X-RAYS (keV)

1.	10 - 15	10.	75 - 90
2.	15 - 20	11.	90 - 105
3.	20 - 25	12.	105 - 120
4.	25 - 30	13.	120 - 140
5.	30 - 35	14.	140 - 160
6.	35 - 45	15.	160 - 190
7.	45 - 55	16.	190 - 220
8.	55 - 65	17.	220 - 260
9.	65 - 75	18.	260 - 300

TABLE 13. SOURCE SPECTRA FOR NEUTRONS

Group	Energy Boundaries (MeV)	Fission Weapon Source Values (Fraction in Group)	Thermonuclear Source Values (Fraction in Group)
1	1.07(-7) - 2.9(-5)	0	0
2	2.9(-5) - 1.01(-4)	0	2.00(-3)
3	1.01(-4) - 5.83(-4)	0	2.40(-2)
4	5.83(-4) - 3.35(-3)	0	1.22(-1)
5	3.35(-3) - 0.111	2.227(-1)	3.65(-1)
6	0.111 - 0.55	1.693(-1)	1.02(-1)
7	0.55 - 1.11	2.159(-1)	8.50(-2)
8	1.11 - 1.83	1.468(-1)	6.20(-2)
9	1.83 - 2.35	1.060(-1)	2.80(-2)
10	2.35 - 2.46	5.743(-3)	5.00(-3)
11	2.46 - 3.01	2.871(-2)	1.90(-2)
12	3.01 - 4.07	5.481(-2)	2.60(-2)
13	4.07 - 4.97	1.177(-2)	1.70(-2)
14	4.97 - 6.36	1.832(-2)	1.80(-2)
15	6.36 - 8.19	1.274(-2)	1.47(-2)
16	8.19 - 10.0	7.342(-3)	1.41(-2)
17	10.0 - 12.2	0.0	2.56(-2)
18	12.2 - 15.0	0.0	7.06(-2)

TABLE 14. SOURCE SPECTRA FOR GAMMA RAYS

Group	Energy Boundaries (MeV)	Prompt Fission Source Values (Fraction in Group)	Delayed Source Values (Fraction in Group)
1	0.02 - 0.05	3.084(-2)	.0363
2	0.05 - 0.1	1.355(-2)	.0580
3	0.1 - 0.2	8.164(-2)	.1052
4	0.2 - 0.3	6.872(-2)	.0942
5	0.3 - 0.4	8.678(-2)	.0835
6	0.4 - 0.6	1.7681(-1)	.1380
7	0.6 - 0.8	1.4017(-1)	.1090
8	0.8 - 1.0	1.0042(-1)	.0835
9	1.0 - 1.33	1.0729(-1)	.100
10	1.33 - 1.66	6.183(-2)	.0644
11	1.66 - 2.0	3.935(-2)	.0424
12	2.0 - 2.5	3.756(-2)	.0401
13	2.5 - 3.0	2.233(-2)	.0218
14	3.0 - 4.0	2.116(-2)	.0182
15	4.0 - 5.0	7.483(-3)	.0054
16	5.0 - 6.5	3.230(-3)	.0
17	6.5 - 8.0	6.790(-4)	.0
18	8.0 - 10.0	1.580(-4)	.0

TABLE 15. DOSE RESPONSE FUNCTIONS FOR NEUTRONS $(\text{rad}/(\text{n}/\text{cm}^2))$

Group	Upper Energy (MeV)	Henderson Tissue	Snyder-Neufeld	Tissue Kerma	Mid-Phantom	Concrete Kerma	Air Kerma	Non-Ionizing Silicon Kerma	Ionizing Silicon Kerma
1	4.14(-7)	0	3.20(-10)	9.36(-12)	5.50(-11)	3.62(-12)	2.43(-10)	0	0
2	1.12(-6)	0	3.22(-10)	4.26(-12)	7.90(-11)	1.63(-13)	1.13(-10)	0	0
3	3.06(-6)	0	3.27(-10)	2.65(-12)	8.50(-11)	1.02(-13)	6.71(-11)	0	0
4	1.07(-5)	0	3.42(-10)	1.62(-12)	1.00(-10)	6.35(-14)	3.70(-11)	0	0
5	2.9(-5)	0	3.88(-10)	1.11(-12)	1.10(-10)	5.00(-14)	2.26(-11)	0	0
6	1.01(-4)	0	5.35(-10)	1.17(-12)	1.15(-10)	7.10(-14)	1.28(-11)	0	0
7	5.83(-4)	0	6.75(-10)	3.67(-12)	1.10(-10)	2.85(-13)	5.62(-12)	0	0
8	3.35(-3)	0	6.07(-10)	1.96(-11)	1.05(-10)	1.58(-12)	3.61(-12)	0	0
9	0.11	2.29(-10)	7.00(-10)	4.00(-10)	1.20(-10)	3.55(-11)	2.67(-11)	0	0
10	0.55	1.12(-9)	1.73(-9)	1.27(-9)	2.00(-10)	1.48(-10)	9.84(-11)	2.0(-11)	1.4(-11)
11	1.11	1.97(-9)	3.30(-9)	2.05(-9)	2.80(-10)	2.61(-10)	1.61(-10)	3.1(-11)	1.7(-11)
12	1.83	2.64(-9)	3.96(-9)	2.63(-9)	5.30(-10)	3.12(-10)	2.95(-10)	3.4(-11)	2.1(-11)
13	2.35	3.09(-9)	4.23(-9)	3.05(-9)	7.00(-10)	3.50(-10)	3.37(-10)	4.2(-11)	2.7(-11)
14	2.46	3.15(-9)	4.33(-9)	3.15(-9)	1.15(-9)	3.20(-10)	4.09(-10)	4.7(-11)	3.0(-11)
15	3.01	3.39(-9)	4.48(-9)	3.43(-9)	1.25(-9)	4.10(-10)	5.38(-10)	4.8(-11)	3.6(-11)
16	4.07	4.01(-9)	4.83(-9)	3.98(-9)	1.75(-9)	5.80(-10)	1.06(-9)	4.8(-11)	5.4(-11)
17	4.97	4.13(-9)	5.43(-9)	4.21(-9)	2.30(-9)	5.40(-10)	1.20(-9)	5.1(-11)	9.0(-11)
18	6.36	4.44(-9)	6.03(-9)	4.50(-9)	2.80(-9)	5.75(-10)	1.05(-9)	5.5(-11)	1.6(-10)
19	8.19	4.61(-9)	6.72(-9)	4.87(-9)	3.50(-9)	7.05(-10)	1.11(-9)	6.6(-11)	5.0(-10)
20	10.0	4.84(-9)	7.08(-9)	5.17(-9)	4.20(-9)	8.20(-10)	1.41(-9)	6.4(-11)	8.1(-10)
21	12.2	5.13(-9)	7.00(-9)	5.74(-9)	4.50(-9)	1.17(-9)	1.93(-9)	6.6(-11)	9.0(-10)
22	15.0	5.46(-9)	7.00(-9)	6.36(-9)	4.90(-9)	1.58(-9)	2.66(-9)	7.5(-11)	8.6(-10)

TABLE 16. DOSE RESPONSE FUNCTIONS FOR GAMMA RAYS $(rad/(\gamma/cm^2))$

Group	Upper Energy (MeV)	Henderson Tissue	Concrete Kerma	Air Kerma	Silicon Kerma
1	0.05	8.37(-11)	5.90(-10)	4.40(-11)	4.13(-10)
2	0.1	3.90(-11)	1.20(-10)	9.75(-11)	7.25(-11)
3	0.2	6.60(-11)	8.00(-11)	5.92(-11)	7.25(-11)
4	0.3	1.22(-10)	1.20(-10)	1.11(-10)	1.17(-10)
5	0.4	1.77(-10)	1.68(-10)	1.63(-10)	1.65(-10)
6	0.6	2.56(-10)	2.42(-10)	2.38(-10)	2.37(-10)
7	0.8	3.50(-10)	3.30(-10)	3.26(-10)	3.28(-10)
8	1.0	4.45(-10)	4.10(-10)	4.10(-10)	4.10(-10)
9	1.33	5.30(-10)	5.05(-10)	5.05(-10)	5.05(-10)
10	1.66	6.44(-10)	6.15(-10)	6.15(-10)	6.10(-10)
11	2.0	7.35(-10)	7.15(-10)	7.13(-10)	7.12(-10)
12	2.5	8.75(-10)	8.40(-10)	8.30(-10)	8.40(-10)
13	3.0	1.08(-9)	9.80(-10)	9.52(-10)	9.85(-10)
14	4.0	1.27(-9)	1.18(-9)	1.12(-9)	1.20(-9)
15	5.0	1.59(-9)	1.46(-9)	1.34(-9)	1.48(-9)
16	6.5	1.76(-9)	1.80(-9)	1.60(-9)	1.83(-9)
17	8.0	2.07(-9)	2.18(-9)	1.90(-9)	2.28(-9)
18	10.0	2.42(-9)	2.65(-9)	2.24(-9)	2.80(-9)

TABLE 17.   DOSE RESPONSE FUNCTIONS FOR X-RAYS

$(rad/(x/cm^2))$ except the gold dose which is $((cal/gm)/(x/cm^2))$

Group	Upper Energy (KeV)	Henderson Tissue	Gold Kerma	Air Kerma	Silicon Kerma
1	15	6.05(-10)	6.39(-14)	4.68(-10)	3.56(-9)
2	20	2.89(-10)	7.32(-14)	2.04(-10)	1.73(-9)
3	25	1.70(-10)	4.82(-14)	1.24(-10)	1.00(-9)
4	30	1.12(-10)	3.44(-14)	8.09(-11)	6.49(-10)
5	35	7.99(-11)	2.59(-14)	5.78(-11)	4.52(-10)
6	45	5.48(-11)	1.83(-14)	4.07(-11)	2.94(-10)
7	55	3.97(-11)	1.23(-14)	3.07(-11)	1.84(-10)
8	65	3.46(-11)	8.96(-15)	2.77(-11)	1.30(-10)
9	75	3.37(-11)	6.80(-15)	2.79(-11)	1.01(-10)
10	90	3.54(-11)	1.65(-14)	3.06(-11)	8.19(-11)
11	105	4.06(-11)	1.93(-14)	3.55(-11)	7.12(-11)
12	120	4.73(-11)	1.53(-14)	4.16(-11)	6.78(-11)
13	140	5.58(-11)	1.22(-14)	4.95(-11)	6.88(-11)
14	160	6.59(-11)	9.68(-15)	5.92(-11)	7.36(-11)
15	190	7.96(-11)	7.54(-15)	7.19(-11)	8.22(-11)
16	220	9.67(-11)	4.83(-15)	8.76(-11)	9.50(-11)
17	260	1.16(-10)	4.56(-15)	1.06(-10)	1.11(-10)
18	300	1.40(-10)	3.61(-15)	1.27(-10)	1.31(-10)

TABLE 18. LOW ENERGY X-RAY DOSE RESPONSE FUNCTIONS
$(rad/(x/cm^2))$ except the gold dose which
is $((cal/g)/(x/cm^2))$

Group	Boundaries (keV)	Gold Kerma	Air Kerma	Silicon Kerma
1	0.1 - 0.2	3.79(-14)	5.349(-8)	2.083(-7)
2	0.2 - 0.3	12.94(-14)	2.618(-8)	1.761(-7)
3	0.3 - 0.4	20.98(-14)	1.381(-8)	1.323(-7)
4	0.4 - 0.5	23.29(-14)	1.339(-7)	1.001(-7)
5	0.5 - 0.6	23.44(-14)	1.279(-7)	6.295(-8)
6	0.6 - 0.7	24.20(-14)	1.118(-7)	4.893(-8)
7	0.7 - 0.8	22.92(-14)	9.043(-8)	3.918(-8)
8	0.8 - 0.9	21.70(-14)	7.450(-8)	3.213(-8)
9	0.9 - 1.0	19.91(-14)	6.198(-8)	2.684(-8)
10	1.0 - 2.0	14.26(-14)	3.477(-8)	2.918(-8)
11	2.0 - 3.0	18.56(-14)	1.189(-8)	7.063(-8)
12	3.0 - 4.0	21.56(-14)	6.083(-9)	3.837(-8)
13	4.0 - 5.0	15.97(-14)	3.935(-9)	2.413(-8)
14	5.0 - 6.0	11.59(-14)	2.601(-9)	1.652(-8)
15	6.0 - 7.0	8.91(-14)	1.898(-9)	1.209(-8)
16	7.0 - 8.0	7.08(-14)	1.418(-9)	9.310(-9)
17	8.0 - 9.0	5.81(-14)	1.100(-9)	7.300(-9)
18	9.0 - 10.0	4.87(-14)	8.773(-10)	5.780(-9)

TABLE 19. ANGULAR QUADRATURES, COSINES AND ANGLES

Index	Quadrature Cosine	Quadrature Weight	Cosine Boundary Lower	Upper	Angle Boundary Lower	Upper
1	-.989401	1.35763(-2)	-1.0	-.97284	180.0	166.6
2	-.944575	3.11268(-2)	-.97284	-.91058	166.6	155.6
3	-.865631	4.75793(-2)	-.91058	-.81542	155.6	144.6
4	-.755404	6.23145(-2)	-.81542	-.69080	144.6	133.7
5	-.617876	7.47980(-2)	-.69080	-.54120	133.7	122.8
6	-.458017	8.45783(-2)	-.54120	-.37200	122.8	111.8
7	-.281604	9.13017(-2)	-.37200	-.18940	111.8	100.9
8	-.095012	9.47253(-2)	-.18940	0.0	100.9	90.0
9	.095012	9.47253(-2)	0.0	.18940	90.0	79.1
10	.281604	9.13017(-2)	.18940	.37200	79.1	68.2
11	.458017	8.45783(-2)	.37200	.54120	68.2	57.2
12	.617876	7.47980(-2)	.54120	.69080	57.2	46.3
13	.755404	6.23145(-2)	.69080	.81542	46.3	35.4
14	.865631	4.75793(-2)	.81542	.91058	35.4	24.4
15	.944575	3.11268(-2)	.91058	.97284	24.4	13.4
16	.989401	1.35763(-2)	.97284	1.0	13.4	0.0

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5. AIR-GROUND AND EXPONENTIAL AIR CORRECTION FACTORS

The ATR data base is a parameterization of infinite air results. Many problems of interest involve the location of a source or detector near the air-ground interface or near the "edge of the atmosphere". A rigorous solution to the treatment of these two extremes would involve the generation of a much larger data base than that required for infinite air. Because such a data base does not exist and its generation was beyond the scope of the present work, an engineering approach was taken in correcting the infinite air results to account for the air-ground interface and the exponential atmosphere.

The earlier versions of ATR utilized a first-last collision model which was dependent on the source height and detector height in mean-free-paths. This model which was developed for neutrons was also used for secondary gamma rays. It was extended for use for prompt gamma rays and modified for use in treating the exponential air correction. It was realized that the logical reasoning behind the appropriateness of a first-last collision model does not hold for secondary gamma rays and when a better data base became available it was incorporated into ATR-3.

The correction factor approach based on a limited data base leads to uncertainties in the results and the user should examine the applicability of ATR for each particular problem based on his accuracy requirements. For all correction factors, corrections are only made to intensity and no change in spectra or angular distribution results from a correction for the air-ground interface or exponential atmosphere.

5.1 AIR-OVER-GROUND FACTORS FOR NEUTRONS AND SECONDARY GAMMA RAYS

For the neutron and secondary gamma ray transport model in ATR, air-over-ground correction factors are based on calculations utilizing the two-dimensional discrete ordinates code DOT.[16] Several dose responses were calculated in an air-over-ground geometry for a series of source altitudes up to 300 m. The calculations were performed with ENDF-IV cross sections in the 22 neutron and 18 photon group structure of ATR. The air and ground compositions employed in the calculations are given in Table 20 and only two separate neutron sources were used at each burst height - the 14 MeV source and the weapon fission source given in Table 21. The source heights used in the calculations were 1, 50,100 and 300 meters.

TABLE 20. AIR AND GROUND COMPOSITIONS
(atoms/b-cm)

Element	Air (ρ = 1.22 g/ℓ)	Ground (ρ = 1.7 g/cm^3)
H		9.7656-3[*]
N	4.0242-5	
Ø	1.0697-5	3.4790-2
Al		4.8828-3
Si		1.1597-2

[*] Read as 9.7656 x 10^{-3}.

Correction factors for air-over-ground radiation transport involve the ratio of the air-over-ground result to the infinite air result at the same slant range and air density. The tissue dose in infinite air was calculated by ATR.

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TABLE 21.   WEAPON FISSION SOURCE

Group	Upper Energy (MeV)	Spectrum
1	15.	0.0
2	12.2	0.0
3	10.0	7.342-3*
4	8.18	1.274-2
5	6.36	1.832-2
6	4.96	1.177-2
7	4.06	5.481-2
8	3.01	2.871-2
9	2.46	5.743-3
10	2.35	1.060-1
11	1.83	1.468-1
12	1.11	2.159-1
13	0.55	1.693-1
14	0.111	2.227-1
15-22	0.00335	0.0

*
Read as 7.342×10^{-3}.

In the air-over-ground calculations, for each source (14 MeV and fission) there are four burst heights and for each burst height, four target altitudes were selected at approximately 0.5, 50, 100 and 400 meters above the ground.

If $D_G(H_S,H_T,R)$ represents the air-ground tissue dose as a function of source height (H_S), target height (H_T) and horizontal range (R), and $D_A(H_S,H_T,R)$ represents the infinite air ATR tissue dose results in a similar functional form, then the correction factor $C(H_S,H_T,R)$ is

$$C(H_S,H_T,R) = \frac{D_G(H_S,H_T,R)}{D_A(H_S,H_T,R)} \qquad .$$

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This correction factor was parametrized as a power series:

$$C\left(H_{S_0}, H_{T_0}, R\right) \cong a_0 + a_1 R + \ldots + a_n R^n \quad ,$$

That is, for a given source height and target height, the correction factor is curve fitted as a function of horizontal range. The number of terms is 4, 5, or 6 depending on which polynomial fit gave the best approximation. For neutrons and secondary gamma rays, two sources, four source heights and four target heights, a total of 281 coefficients were necessary to adequately represent the selected data base.

The correction factors are applied differently depending on the source and detector heights, see Fig. 3.
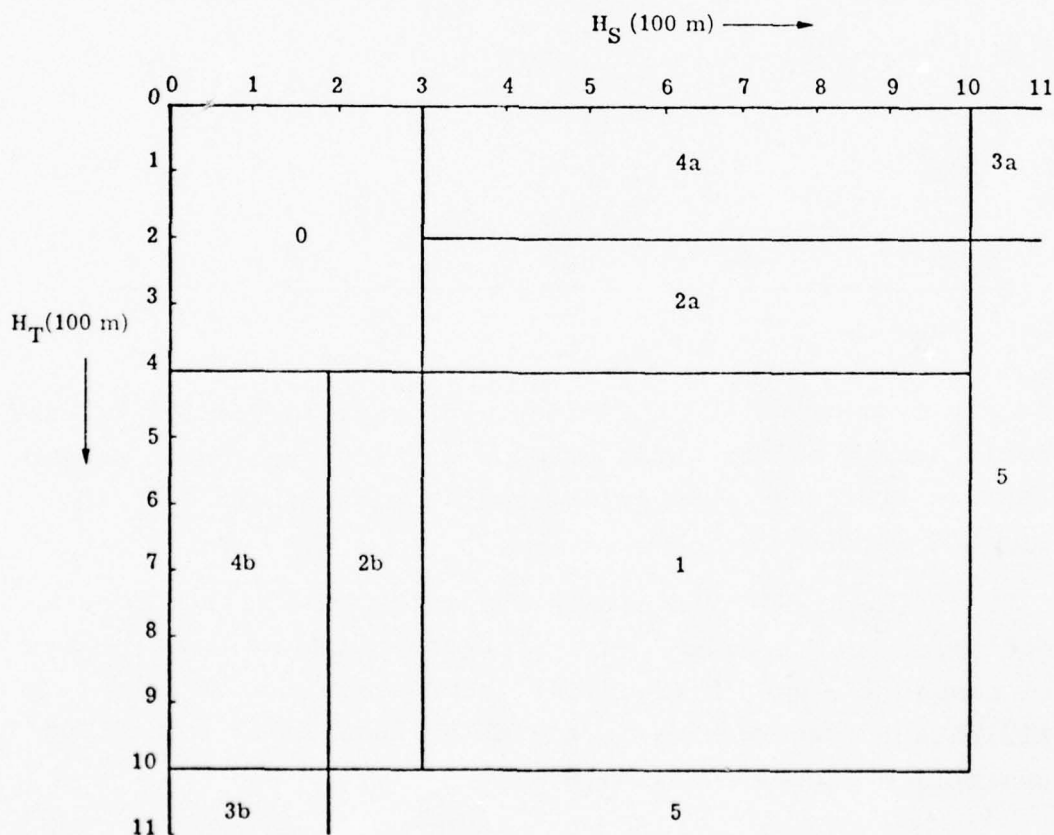
Figure 3. Regions of Interest for Air-over-Ground Correction Factors

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For a geometry configuration in region 0, (i.e. source less than 300 meters and detector less than 400 meters) the correction factor $C(H_S, H_T, R)$ is evaluated from the parametrization. In region 5, $C(H_S, H_T, R) = 1$. For the other regions the correction factor is computed by the following formulae:

1. $$C_1 = 1 + \{C(300, 400, R) - 1\} \cdot \frac{1000 - H_T}{600}$$

   $$C(H_S, H_T, R) = 1 + (C_1 - 1) \cdot \frac{1000 - H_S}{700}$$

2a. $$C(H_S, H_T, R) = 1 + \{C(300, H_T, R) - 1\} \cdot \frac{1000 - H_S}{700}$$

2b. $$C(H_S, H_T, R) = 1 + \{C(H_S, 400, R) - 1\} \cdot \frac{1000 - H_T}{600}$$

3a. $$C(H_S, H_T, R) = 1 + \{C(300, H_T, R) - 1\} \cdot \frac{200 - H_T}{200}$$

3b. $$C(H_S, H_T, R) = 1 + \{C(H_S, 400, R) - 1\} \cdot \frac{200 - H_S}{200}$$

4a. $$C_1 = 1 + \{C(300, H_T, R) - 1\} \cdot \frac{1000 - H_S}{700}$$

   $$C(H_S, H_T, R) = C_1 + \{C(300, H_T, R) - C_1\} \cdot \frac{200 - H_T}{200}$$

4b. $$C_1 = 1 + \{C(H_S, 400, R) - 1\} \cdot \frac{1000 - H_T}{600}$$

   $$C(H_S, H_T, R) = C_1 + \{C(H_S, 400, R) - C_1\} \cdot \frac{200 - H_S}{200} \qquad .$$

These calculated correction factors then multiply the infinite air results in ATR to produce the air-ground corrected data. The correction factors from the parametrization of the 14 MeV source are used for source energies above 5 MeV. The correction factors from the fission source are used for source energies below 5 MeV. Due to the parametrization in the different spatial regions some minor changes in shape can occur near the boundaries but these "perturbations" are generally less than 10%. Since the correction factors are based on a tissue dose response, values for other responses may be in error.

5.2 AIR-OVER-GROUND FACTORS FOR PHOTONS

There is no data base or first-last collision model similar to that developed for neutrons with which to correct for air-ground interface effects on the transport of photons in air. Because of the predominant forward scattering distribution of high energy photons, there is less of a perturbation of infinite air results due to the air-ground interface.

The correction factors that were employed for the prompt gamma-ray transport were based on a modification of French's[17] first-last collision method. Because the Klein-Nishina scattering distribution is peaked in the forward directions for gamma-rays, those gamma rays which leave the source in directions pointing away from the detector point (or target) will have little effect on the dose at the detector. This is true for photon transport in both homogeneous atmosphere and air-over-ground geometries. Calculations by Woolson in infinite homogeneous air[18] and air-over-ground[19] indicate that in both cases the contribution to the dose from backward directed photons is generally about two orders of magnitude or more below the dose contribution from forward directed photons. This suggests a revision of French's method to account for the fact that the most important effect of the ground is to remove the contribution to the dose from photons which have left the source in directions toward the detector and scattered into the ground.

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The original first-last collision model does not distinguish between the directionality of the source particles in accounting for the effect of ground removal of first collisions or for the effect of removal of the last flight photons due to the presence of the ground. To account for these "effects" the model was modified for prompt gamma rays by assuming that a fraction of the photons are unaffected. That is

$$F_\gamma = (1-x) + xF$$

where F_γ is the prompt gamma-ray correction factor, F is the first-last collision model correction factor and the parameter x is a number between zero and unity. The lower the value of x the greater the importance of directionality, i.e., the effect of ground removal of photons is only important for the fraction x of isotropically emitted photons and it is assumed that $(1-x)$ photons are not affected by the ground. The value of x was chosen, rather arbitrarily, to be .25 and does not vary with photon energy.

The correction employed in ATR for the air-ground interface effect on prompt photon transport can be expressed by the equation

$$\phi(H_S, H_T, R) = F_\gamma(H_S) \; F_\gamma(H_T) \; \phi_\infty(R)$$

where $\phi(H_S, H_T, R)$ is the ATR result for source and target heights H_S and H_T respectively at range R and $\phi_\infty(R)$ is the infinite air fluence at range R. The functions $F_\gamma(H_S)$ and $F_\gamma(H_T)$ are the modified source and target first-last collision model correction factors for prompt gamma rays. These factors are given in Table 22 as a function of the number of mean-free-paths from the ground.

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TABLE 22. AIR-OVER-GROUND CORRECTION FACTORS
FOR PROMPT GAMMA RAYS

Mean Free Path	$F(H_S)$	$F(H_T)$
0.00	0.834	0.875
0.01	0.843	0.882
0.02	0.847	0.887
0.05	0.855	0.897
0.10	0.867	0.910
0.25	0.893	0.935
0.50	0.921	0.959
0.75	0.943	0.973
1.00	0.961	0.981
1.50	0.983	0.991
2.00	0.992	0.995
3.00	1.000	1.000

This method of correcting for the air-over-ground per-
turbations in gamma ray transport does not account for the
increased dose over the infinite homogeneous air dose for
ground ranges close to the source for source heights within,
say, 100 meters of the ground which is due to albedo scattering
in the ground.

Correction factors for the air-over-ground interface
effect for X-ray transport were derived from a series of photon
transport calculations performed by Coleman to generate EMP
sources due to the air-ground asymmetry. Coleman reported
results for 1 meter and 200 meter source heights and horizontal
ranges to 1000 meters.

An analysis of this data indicated that doses at targets
above the source point for most cases were within 10-20% of the
infinite medium doses for the same slant range. This data also
indicated a general trend that the dose at ground targets was
on the order of 50% below the infinite medium dose.

A two dimensional air-over-ground correction function $C_x(R,y)$ was generated from Coleman's data for X-ray transport. This function is used in the following manner

$$\phi(H_S, H_T, R) = C_x(R,y) \, \phi_\infty(R) \quad ,$$

where $\phi(H_S, H_T, R)$ is the ATR result for source and target heights H_S and H_T respectively at range R, $\phi_\infty(R)$ is the infinite medium fluence at range R and $y = H_T/H_S$. Tabulated values of the correction factor $C_x(R,y)$ are given in Table 23. Functional values for given R and y arguments are found by interpolation in the table. Correction factors are employed in this model only if the target height is within 200 meters of the ground.

TABLE 23. VALUES OF THE X-RAY AIR-
GROUND CORRECTION FACTOR

Range (m)	$y = H_T/H_S$		
	0	.5	1.0
50	0.12	0.201	.412
95	0.16	0.35	.72
140	0.17	0.37	.85
185	0.19	0.42	.86
225	0.224	0.45	.87
275	0.286	0.54	.89
325	0.39	0.65	.92
375	0.48	0.68	1.0
425	0.48	0.70	1.0
475	0.48	0.72	1.0
525	0.49	0.73	1.0
575	0.50	0.74	1.0
645	0.50	0.83	1.0
715	0.50	0.83	1.0
785	0.50	0.83	1.0
855	0.50	0.83	1.0
925	0.55	0.85	1.0
1000	0.55	0.90	1.0

5.3 CORRECTION FACTORS FOR EXPONENTIAL ATMOSPHERE

Due to the decrease in atmospheric density near the
"edge" of the atmosphere, radiation transport results may
exhibit a significant departure from results which are scaled
by the mass thickness of air along a line from the source to
detector. At altitudes above 40 km, the dose may deviate sig-
nificantly from one dimensional, density scaled results because
of significant changes in atmospheric density over distances
comparable to a particle mean-free-path.

Corrections for non-uniform air density effects were ob-
tained by extending the first-last collision model to include
the density variation versus altitude in the numerical integra-
tion scheme. The first collision correction factor for source
altitude was obtained by numerical integration of the equation

$$F(H_S) = \frac{\mu_T}{2} \int_0^\infty \int_{-H_S}^\infty \frac{W(Z)X\bar{\rho}(Z)e^{-\mu_T\bar{\rho}(Z)\sqrt{X^2+Z^2}}}{X^2+Z^2} \, dXdZ$$

where μ_T is the total cross section in air in cm^2/gm, $W(Z)$ is
a weighting factor given by $F(H_S+Z)$ to account for multiple
scattering and is obtained by an iteration of the above equation.
A term to account for reflection is zero, since neutrons are
not reflected from the top of the atmosphere.

The last-collision correction for target altitude was ob-
tained from numerical evaluation of the above integral without
the weighting function. The numerical results for $F(H_S)$ and
$F(H_T)$ are listed in Table 24 as a function of altitude in terms
of the mean-free-path to the top of the atmosphere. These cor-
rection factors were applied uniformly to the scaled infinite-
air results in ATR for both neutron and secondary gamma rays.

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TABLE 24. EXPONENTIAL AIR CORRECTION FACTOR FROM
THE FIRST-LAST COLLISION MODEL AS A
FUNCTION OF MFP FROM THE TOP OF THE
ATMOSPHERE

H(MFP)	$F(H_S)$	$F(H_T)$
0	0	0
0.010	0.067	0.180
0.030	0.092	0.229
0.060	0.133	0.300
0.090	0.166	0.350
0.140	0.210	0.408
0.210	0.271	0.482
0.320	0.373	0.585
0.490	0.491	0.676
0.770	0.642	0.793
1.200	0.808	0.890
2.000	0.920	0.967
3.100	0.975	0.980
4.900	0.985	0.990
7.900	0.996	0.998
H > 7.9	1.000	1.000

Verification of the adequacy of this model is not complete due
to the lack of an adequate data base.

There are no high altitude correction factors in ATR for
prompt gamma rays and for X-rays. Results at high altitudes
for these sources are infinite air results scaled to the actual
mass thickness of air. When an adequate data base becomes avail-
able, correction factors should be included for photon sources.

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In summary, air-ground correction factors based on Henderson tissue dose are used to correct the intensity of infinite air results for neutrons and secondary gamma rays. Only intensity corrections are made to energy-angular distributions and corrections are based on results for a 14 MeV source (for source energies greater than 5 MeV) and on results for a fission source (for source energies less than 5 MeV). A modified first-last collision model is used for prompt gamma rays and a data base is utilized for X-rays. Exponential atmosphere corrections are based on a modified first-last collision model for neutrons and secondary gamma rays and no corrections are applied to prompt gamma ray and X-ray results. As a more complete data base becomes available, both the air-ground and exponential atmosphere correction factors should be reevaluated.

6. ATR COMMANDS

In the development of ATR, attempts were made to utilize a command structure which is user oriented, simple and convenient yet provide a wide variety of options for describing the problem. The ATR command structure can be divided into four separate groups:

- Source
- Geometry
- Output
- Execution

The source commands deal with the description of the source energy distribution and intensity for the various components of radiation. The geometry commands are used to describe the burst, ground and detector locations. The output commands are used to insure that the required quantities are available in the desired units. The execution commands provide the means of performing several calculations without repeating all the input.

All of the commands utilize the same basic structure; a typical command is of the general form:

*<COMMAND WORD>,<UNITS DEFINITION>,<LIST OF VALUES>

All commands must begin with an asterisk. If an ATR command is too long to fit on a single 80-character line, the command may be continued on subsequent lines not beginning with an asterisk. The restrictions on continuation are that no single part of an ATR command, such as a number, may itself be split into two lines and there should be at least two numbers (values) on the first card image. The command word is generally a mnemonic name for the type of action to be taken.

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Figure 4 illustrates the various general commands and the portion of ATR affected by each. A list of the command words is given in Table 25 with a verbal description of the command words given in Table 26, and a summary description of the ATR commands is given in Table 27.

The second field of the general command, or units definition, is delimited by commas. The units definition field, which is optional, serves to explain the meaning of the numbers in the list of values that follows. Typical units include:

MEV	-	Energy values
KEV	-	Energy values
PER MEV	-	Source values
COS	-	Cosine angle values

Specific sets of unit definitions are appropriate for each command. A default unit definition has been selected from the set appropriate to each command, and is used whenever the units definition with its surrounding commas are omitted.

The list of values field of an ATR command is used to specify the numerical data a command may require. A number in a list may appear in a variety of forms to suit the particular user or problem. For example, some of the forms in which the number 400. may appear are as follows:

$$400 \quad 400. \quad 4.E+2 \quad 4.+2 \quad 4+2 \quad 4000-1$$

At least one number must appear in a list of values element. Two or more numbers are separated from one another by the occurrence of one or more blank characters. Therefore, the user is restricted from specifying a number in which internal blanks appear, or which is split on two or more card images. A further restriction exists upon the magnitude of such

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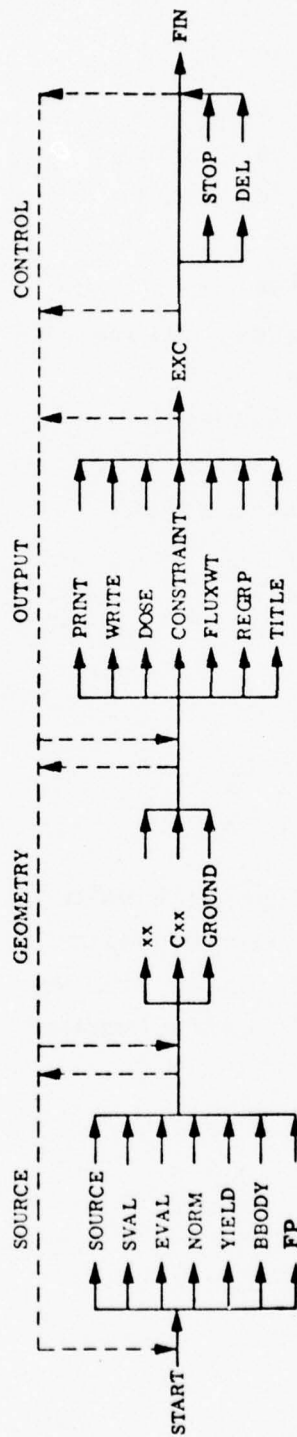
Figure 4. Logical Flow of Control of ATR Commands

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TABLE 25.   LIST OF COMMANDS

1. *z-SOURCE(i) value
2. *z-SVAL, units, values
3. *z-EVAL, units, values
4. *z-NORM value
5. *z-YIELD value
6. *BBODY-y, units, values
7. *FP-y, value
8. *xx, units, value(s)
9. *Cxx, units, value(s)
10. *GROUND, units, value
11. *EXC, 4PIRSQ
12. *DEL command(s)
13. *STOP
14. *FIN
15. *TITLE n
16. *PRINT/z/(i_1 i_2 ...)
17. *WRITE/z/(i_1 i_2 ...)
18. *DOSE/z/
19. *CONSTRAINT/z/(xx i value), units
20. *FLUXWT/z/, units, values
21. *E-REGRP/z/, units, values
22. *A-REGRP/z/, units, values

TABLE 26. SYNOPSIS OF ATR COMMAND WORDS

SOURCE(i)   — indicates that the ith source option will be chosen

SVAL   — indicates that an energy dependent source intensity will be entered

EVAL   — indicates that the energy group boundaries will follow

NORM   — source normalization value follows

YIELD   — yield of the weapon

BBODY   — indicates that a black body X-ray source spectrum will be specified

FP   — indicates parameters for fission product source

xx   — indicates that the geometry component and associated values will follow

Cxx   — indicates the location of constant response calculation

GROUND   — specifies the ground elevation above sea level

TITLE   — alphanumeric character string identifying the problem

PRINT   — specifies which response option will be printed as output

WRITE   — indicates which response options will be written on an external storage device

DOSE   — indicates types of dose to be calculated

CONSTRAINT   — indicates that the coordinates for a constant response value are to be determined

FLUXWT   — fluence weighting factors which are to be input

E-REGRP   — regroups energy dependent fluences into desired energy groups

TABLE 26. SYNOPSIS OF ATR COMMAND WORDS (Cont'd.)

A-REGRP   -   regroups angular dependent fluences into
                  desired angular bins

EXC   -   an action command to execute the problem
                  specified by prior input

DEL   -   deletes individual geometry or output commands

STOP   -   indicates the end of a problem, initializes
                  input flags

FIN   -   indicates the end of a session

TABLE 27. ATR COMMAND SUMMARY

Command Type	Command List **	Description
SOURCE	*z-SOURCE(i) value	Internal (i=1,2,3) Neutrons, i=1-3, fission, thermonuclear, 14 MeV Gamma-Rays, i=1, fission X-rays, i=1, black body (see BBODY command) External (i=4,5,6) All types, i-4,5, histogram, point Neutrons, i-6, fission/fusion
	*z-SVAL, units, values	Source values to be read as input
	*z-EVAL, units, values	Source energy values to be read as input
	*z-NORM value	Source normalization value in particles/KT
	*z-YIELD value	Source yield in KT
	*BBODY-T, units, values	Black body temperatures (keV or MeV) in weighted spectrum (up to five temperatures)
	*BBODY-W values	Weight in spectrum associated with each black body temperature
	*BBODY-E, units, value	Total energy output of x-rays in spectrum (KT, keV or MeV)
	*FP-y, value	Defines the total yield (y=Y) and the fission fraction (y=F) for use in fission product gamma ray calculations
GEOMETRY	*xx, units, value	Coordinate specifications: HS, HT, RH. RS or AN
	*Cxx, units, value	Coordinate specifications for constant response calculation
	*GROUND, units, value	Ground height above sea level

**

z - Denotes source particle type: N for neutron, G for gamma rays, X for X-ray.

/z/ Denotes output particle type: Same as above plus NG for secondary gamma rays, GG for secondary plus primary gamma rays and FP for dose values due to fission product gamma rays and is used with DOSE and CONSTRAINT. T indicates total results and is used with PRINT, DOSE and CONSTRAINT.

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TABLE 27. ATR COMMAND SUMMARY (continued)

Command Type	Command List	Description
OUTPUT	*TITLE n	Alphanumeric problem descriptor, n = up to 74 characters
	*PRINT/z/(i₁ i₂ ...)	Prints desired responses from list (i₁ i₂ ...)
	*WRITE/z/(i₁ i₂ ...)	Writes desired responses on external tape or disc unit
	*DOSE/z/	Calculates dose versus coordinate value for multiple values specified in *xx
	*CONSTRAINT/z/(xx i value)	Calculates xx at which specified constant response value of type i occurs for fixed geometry coordinates given by *Cxx
	*FLUXWT/z/, units, values	Reads in external factor for weighting flux by energy group
	*E-REGRP/z/, units, values	Regroups energy dependent responses
	*A-REGRP/z/, units, values	Regroups angle dependent responses
CONTROL AND	*EXC, 4PIRSQ	Executive control command which initiates all commands listed above it. *EXC command followed by comma if 4πR2 responses desired in output, i.e., *EXC
DELETE	*DEL GEOM	Deletes individual commands so that these commands can be altered from problem to problem without having to specify the entire problem each time
	*DEL DOSE	
	*DEL CONSTRAINT	
	*DEL A-REGRP	
	*DEL E-REGRP	
	*DEL PRINT	
	*DEL WRITE	
	*DEL FP	
	*STOP	Nullifies all previous input commands by initializing input flags
	*FIN	Signifies end of run, calls exit from ATR

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numbers since a number is interpreted as a function of up to
three integer parts (a whole part, a fractional part, and an
exponent), none of the parts of a number may exceed in magnitude
the greatest integer value appropriate to the host machine, nor
can the number generated from these three parts exceed the host
machine's allowable range of representable numbers.

There are three different numeric formats in which
data may be input:

1. A string of numbers all separated by one or more
    blank characters from each other.

2. A starting and ending number separated by an incre-
    ment specification in parentheses.

3. A repetition factor followed by an asterisk(*)
    character followed by the number to be repeated.

Numeric entries of all three types may be mixed and can be used
in any order.

A detailed discussion of the input commands is given in
the next four sections.

6.1   SOURCE COMMANDS

The source commands are number 1-7 in Table 25.
There are several ways that an ATR source spectrum can be
specified. For each particle in ATR there are standard,
built-in source spectra which can be used or new values may
be input. The following specific commands may be used.

*z-SOURCE(i) value

z = N, G, X for neutrons, prompt gamma rays, and X-rays re-
spectively, and has the same meaning for other source
related commands.

i = 1, 2, 3, 4, 5, or 6 with meanings that are described in
Table 28 for each particle.

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TABLE 28. SOURCE OPTIONS FOR ATR

Value of i in *z-SOURCE (i)	Neutrons	Prompt Gamma-Rays	X-Rays
1	Fission	Fission	Black Body
2	Thermonuclear	Not Used	Not Used
3	12.2-15 MeV	Not Used	Not Used
4	Histogram	Histogram	Histogram
5	Point	Point	Point
6	Fission/ Fusion Mix	Not Used	Not Used

For example, the command: *N-SOURCE(1) will select the internal spectrum for the neutron fission source (see Table 13 for the actual values) which then will stay in effect until it is replaced by another neutron source command. (Note that the neutron detector energy spectrum covers a wider range than the source spectrum.) For X-rays the *X-SOURCE(1) command must be accompanied by *BBODY-y commands to specify the parameters of the black body spectrum.

Histogram and point values of the source spectrum can be entered by using the *z-SOURCE(4) and the *z-SOURCE(5) commands respectively in conjunction with the *z-SVAL and *z-EVAL commands which are used to enter source values and corresponding energy values. Only the *z-SVAL is needed if the source values being entered correspond to the internal energy structure. The source values must be placed in sequence of low to high energy values. When both the source and corresponding energy values are input, then the energy values either correspond to histogram boundary values by having one more energy value than source value, or they correspond to point source values in which case there will be the same number of energy and source values. Again, the energy values must be specified in ascending order, and the source values must correspond to the energy values.

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In the event that external energy values are specified, routines are called by ATR to regroup the source values to the internal energy-source group structure. The user must exercise caution when the input spectrum to be regrouped contains extreme gradients at the end points or embedded zero source values. The maximum number of energy or source values is arbitrarily limited to 50.

Source spectrum normalization (in units of particle/KT) and yield (in units of KT) can also be affected by using the *z-NORM and the *z-YIELD commands. The spectrum will not be normalized if *z-NORM is not specified (standard internal spectra are normalized to 1). The default yield is 1 KT. The total source output which is printed with the source spectrum configuration is the product of the normalization and yield.

Some care must be exercised in source specification when running sequential problems with ATR. When both source and energy values are needed it is not adequate in sequential problems to specify only the source values. Subsequent problems in which only source values are given will assume the source values apply to the internal energy group structure. Therefore both the energy and source values must be specified every time one or the other is to be changed.

It is a common programming technique for a user to set up energy and source values in one problem, changing only the yield and/or the normalization for subsequent problems. When both the yield and the normalization are subsequently specified, there is no confusion. When the normalization is specified at least once, and only the yield is changed, ATR will always normalize the source spectrum to the given normalization before administering the yield. If the yield is never specified, it is assumed to be unity. A problem can arise if the normalization is never specified. Because ATR assumes no inherent normalization,

it integrates the source and uses the result as the normalization (but does not save that number as the normalization value for subsequent problems), and then administers the yield. Therefore, if only the yield is changed in the next problem, ATR will integrate the source spectrum it used for the previous problem to arrive at a new normalization. In other words, the normalization for the next problem is essentially the total output from the previous problem. Therefore a normalization should be specified at least once even if the standard internal source spectra are used.

The "value" is only meaningful for z=N and i=6 in which case the value (between 0 and 1) represents the fraction of fission neutrons relative to the total number of neutrons (fission + 12.2 - 15 MeV).

Examples:

1. *N-SOURCE(2)

   which selects the internal thermonuclear spectrum (no other commands are necessary for the source spectrum specification).

2. *G-SOURCE(1)

   which selects the internal prompt gamma ray fission spectrum.

3. *X-SOURCE(4)

   which means that accompanying *X-SVAL and optional *X-EVAL command(s) specify an external X-ray histogram source.

4. *N-SOURCE(6)   .5

   which selects a neutron source of fission/fusion (i.e., 12.2 - 15 MeV) mix each contributing one-half to the total source spectrum.

*z-SVAL, units, values

z   = N, G or X.

units = PER MEV, PER KEV, PER GROUP, and defines the units on the
        source values. If the units are not specified then the
        default choice is set internally to PER GROUP.

values= source values corresponding to either the internal energy
        structure or the energy values read in by the *z-EVAL
        command. The order is assumed to be from low energy to
        high energy.

For X-ray sources and when the *X-SVAL command is used alone
without the *X-EVAL command (see below) then the source spectrum
is represented in a 20 group structure: The two summary groups
followed by the standard 18 groups. When both the *X-SVAL and
*X-EVAL commands are used, the low energy groups are regrouped
into the internal 18 fine groups and the spectrum above 10 keV
is regrouped into the high energy 18 groups for internal repre-
sentation. The output will appear in the 20 group structure
as discussed above.

Examples:

1. *N-SVAL .01 10 33 100 21.

    which defines the neutron source values for the low
    five energy groups. Other groups are automatically
    filled with zeros.

2. *N-SVAL, PER GROUP, .01 10 33 100 20.

    which has precisely the same effect as Example 1.

3. *X-SVAL, PER KEV, .2 .2 1 .5 .33 .1 .1 .1

    which puts source values into the lowest eight energy
    groups of the X-ray source spectrum where the first
    two groups are .1-1. keV and 1. - 10 keV.

*z-EVAL, units, values

z   = N, G, X.

units = MEV, KEV. The default unit is MEV for neutrons and
        prompt gamma rays and KEV for X-rays.

values = source energy boundary values (if option (4) was
         chosen) or source energy point values (if option (5)
         was chosen). The order is assumed to be from low to
         high energy values.

    Examples:

    1. *N-EVAL 1E-7 1E-4 2E-2 .11 .56 2 5 12.2 15

        which defines the source energy values in MeV for
        neutrons.

    2. *X-EVAL, KEV, 10 50 170 235

        which defines the X-ray source energy values in keV
        although the unit designation is not necessary since
        the default unit definition is keV for X-rays.

*z-NORM value

z   = N, G, X.

value = source normalization in particle/KT. The default value
        of the internal source spectra is 1 and there is no ex-
        plicit unit definition for this command.

    Examples:

    1. *N-NORM 2+23

        which normalizes the neutron spectrum to the value of
        $2 \cdot 10^{23}$ neutrons/KT.

    2. *G-NORM 1

        which normalizes the prompt gamma ray source spectrum
        to 1 gamma ray/KT.

*z-YIELD value

z   = N, G, X.

value = source yield in KT. The default value of the source
        yield is 1 and there is no explicit unit definition
        for this command.

    Examples:

    1.   *N-YIELD 100

         which produces a yield for neutrons of 100 KT.

    2.   *G-YIELD .2

         which produces a prompt gamma-ray yield of .2 KT.

*BBODY-y, units, value(s)

y   = one of E, T or W representing the total energy
              normalization, black body temperature or weight
              associated with each black body component.

units   = KEV, MEV for y=T (default unit in KEV) and is KEV,
              MEV, KT (kiloton) for y=E (default unit is KT). y=W
              indicates the fraction of energy in each black body
              component.

value(s) = total energy value or temperature values or weight
           values.

    This command only applies to X-ray source spectra which
are described by components represented by a black body dis-
tribution. The black body spectrum specified in terms of
frequency, ν, is written in standard notation

$$U(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{h\nu/KT}-1}$$

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and the total energy released is,

$$\int_0^\infty U(E) \, dE = \frac{8\pi (KT)^4}{c^3 h^3} \int_0^\infty \frac{X^3 dX}{e^X - 1} = \frac{8\pi (KT)^4}{c^3 h^3} \left(\frac{\pi^4}{15} \right)$$

where $X = h\nu / KT$.

If we define the energy normalized spectrum by:

$$g(E) \, dE = \frac{15}{\pi^4} \frac{X^3 dX}{e^X - 1}$$

so that

$$\int_0^\infty g(E) \, dE = 1 \quad ,$$

then the correspodning number spectrum is given by:

$$f(E) \, dE = \frac{15}{\pi^4} \cdot \frac{1}{KT} \frac{X^2 dX}{e^X - 1} \quad .$$

The total number of photons emitted for an energy normalized spectrum is,

$$\int_0^\infty f(E) \, dE = \frac{15}{\pi^4} \frac{1}{KT} \int_0^\infty \frac{X^2}{e^X - 1} \, dX \quad .$$

It can be shown that

$$\int_0^\infty \frac{X^2}{e^X - 1} \, dX = \xi(3) \cdot \Gamma(3) = 2.404$$

where ξ is the Riemann Zeta function and Γ the gamma function
and

$$\int_0^\infty f(E) \, dE = \frac{15}{\pi^4} (2.404) \frac{1}{KT} = \frac{1}{2.7(KT)} = \frac{.37}{KT}$$

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so that when

$$\int_0^\infty g(E) \ dE = 1$$

then

$$\int_0^\infty f(E) \ dE = .37/KT \quad .$$

For a series of black body energy weights W_i such that $\sum W_i = 1$, and for a total energy output E_T, then the number of photons in energy group (E_g, E_{g+1}) is given by

$$N_g = \frac{15}{\pi^4} E_T \sum \frac{W_i}{KT_i} \int_{E_g/KT_i}^{E_{g+1}/KT_i} f'(E) \ dE$$

where $f'(E) = E^2/e^E - 1$ and the total number of photons is

$$N_T = E_T(.37) \sum \frac{W_i}{KT_i} \quad .$$

Notes on black body source spectrum specification:

1. If no $y=E$ command is specified, then the default value $E=1$ keV will be used.

2. If only one value is given on the $y=T$ command and no $y=W$ command is present, then W_1 is set to 1 automatically.

3. If more than one value is given by the $y=T$ command, then there must be the same number of values given by the $y=W$ command.

Examples:

1. *X-SOURCE(1)
    *BBODY-E .2
    *BBODY-T 25

which specifies one black body x-ray spectrum with the following parameters in terms of Eq. (1):

$$E = .2 \text{ KT} \quad , \quad T_1 = 25 \text{ keV} \quad , \quad W_1 = 1 \quad .$$

2. *X-SOURCE(1)
    *BBODY-E 20
    *BBODY-T, KEV, 3 12 28
    *BBODY-W .5 .2 .3

    which specifies a composite of three black body spectra with the following parameters: N=3, E = 20 KT, T_1 = 3 KEV, T_2 = 12 KEV, T_3 = 28 KEV, W_1 = .5, W_2 = .2, W_3 = .3. That is 50% of the energy is represented by a 3 keV black body spectrum, 20% by a 12 keV and 30% by a 28 keV spectrum.

*FP-y values

y   = Y for defining the yield in KT
     = F for defining the fission fraction

value = yield in KT or fission fraction

Since the fission product model is source spectrum independent, these are the only commands that are needed. The fission fraction is preset to one in ATR and is the default value. There is no default value for the yield.

Examples:

1. *FP-Y   100
    *FP-F   .5

    represents a weapon yield of 100 KT and a fission fraction of .5.

6.2 GEOMETRY

The geometry configuration for ATR is illustrated in Fig.2 (pg. 17) where the component coordinates are:

H_S(HS) = source altitude

H_T(HT) = target altitude

R_S(RS) = slant range

R_H(RH) = horizontal range

θ (AN) = slant angle

Three consistent component specifications define a complete geometry configuration with respect to the ground level (as long as one of them is either HS or HT), and the other two components can be calculated from the three. Therefore, ATR requires the specification of three geometry components, one of which may have up to 50 different values. The specified output results are then displayed for the various geometry combinations. The format of the input command is

*xx, units, values

where xx is replaced by one of HS, HT, RS, RH, AN. The unit options include most of the reasonable units that are appropriate. Values may be specified in a list separated by blanks or in the format: n_1 (n) n_2, signifying values ranging from n_1 to n_2 in steps of n. In this case n_2 must be arithmetically greater than n_1.

Two of the possible geometry configurations result in ambiguities. When RH, RS and HT are specified, there is no inherent information whether HS should be placed above or below HT. In order to resolve the ambiguity the characters "+" and "-" should be used with the *HT command to indicate that HS should be placed above or below HT respectively (e.g., *HT - 1000). The other ambiguity occurs when RH, RS and HS are specified and the placement of the target height is in question. In this case, the + and - characters are used with the *HS command to place the target above or below the source respectively. If no character is specified then the default is +.

There is also an option in ATR to move the ground to a desired altitude. It is effected by the *GROUND command and

all specifications involving HS and HT are interpreted <u>relative</u> <u>to the ground</u>. When sequential runs are computed with ATR, the ground is not automatically reset to zero unless respecified by another *GROUND command or a *STOP command is encountered.

To specify the fixed coordinates for a constraint calculation, the command: *Cxx should be used in conjunction with the *CONSTRAINT command. In this case xx has the same meanings and options as the other geometry components (except RS, the slant range, is not allowed as it is the geometric component to be determined by the constraint problem).

*xx, units, value(s)

xx   = one of RH, RS, HT, HS and AN denoting horizontal range, slant range, target height, source height, and slant angle respectively (Fig. 2).

units   = one of M (meters), KM, MILE, YD, KFT, and FT for the distance specification and one of DEG (degrees), RAD (radians), and COS (cosine) for the angle specification. Because of the symmetry of the geometry configuration about the source the range of admissible angles is from $-90°$ to $+90°$. Default unit for the distance specification is M (meters) and for angle it is DEG (degrees).

value(s) = one or more values of the corresponding geometry component. The maximum number of values for any coordinate is arbitrarily fixed at 50.

As mentioned above, three of the geometry commands define a complete ATR geometry. Each geometry component may have several values in principle; however, the intended use is for two of the components to have single values and the third component to have one or more running values. Another typical use is to have multiple values for two components and one value for the third, in which case the two components with the multiple values will be successively paired and used with the single value of the third component.

There is a special unit definition option (GM) for xx = RS which is allowed if the following geometry configuration is specified: HS, HT, RS. In this case the values associated with the xx = RS command are interpreted as g/cm^2 of the slant range. The GM unit option is restricted to this configuration only.

Examples:

1. *HT +, KM, 1
   *RS, KFT, .5 (.5) 10
   *RH 100

   which specifies the target height at 1 kilometer, several values of the slant range starting at .5 kilofeet and ending at 10 kilofeet in steps of .5 kilofeet, and the horizontal range at 100 meters. Note that the coordinates may be specified in different units. Also, the source altitude will be calculated to be above the target altitude.

2. *HS 2000
   *AN, DEG, 10 (10) 80
   *RS, KM, 1

   which specifies the source altitude at 2000 meters, the slant angle ranging from 10 degrees to 80 degrees in steps of 10 degrees, and a slant range of 1 kilometer. The DEG unit specification for the slant angle is superfluous since it is the default unit.

3. *HS, KM, 2
   *HT, KM, 2
   *RS, GM, 50 120 380 410 550

   which specifies coaltitude source and target at 2 kilometers above the ground and the slant range of 5 different values in units of g/cm^2.

*Cxx, units, value(s)

xx   = RH, HT, HS or AN.

units   = same as above.

value(s) = one or more values specifying the geometry component.

Two of these constraint geometry commands must accompany the *CONSTRAINT command with one of the geometry components having a single value and the other having one or more values. If both have more than one value then ATR will arbitrarily pick the first value of one of the coordinates as the fixed value.

Examples:

1. *CHS, KM, 10
    *CAN -90 (10) 90

    which defines the fixed coordinates for a constraint calculation. The source altitude is fixed at 10 kilometers and the slant angle has several values between -90 degrees and +90 degrees in steps of 10 degrees.

2. *CHT, KFT, 0 20 50 80 150 180
    *CAN 0

    which specifies six different configurations for the target altitude in kilofeet and zero slant angle.

*GROUND, units, value

units = same as distance units above.

value = distance value of the ground relative to sea level for the ATR problem geometry.

If this command is not specified then sea level will be used for the ground level. If this command is specified, corresponding HS or HT specifications are interpreted relative to the ground level.

Examples:

1. *GROUND, KM, .5

    which specifies the ground to be at half of a kilometer above sea level.

2. *GROUND 500

    which has the same effect as example (1) since the default unit definition is meters.

6.3 OUTPUT

This section contains the description of commands that either directly or indirectly affect the output of results from ATR. By specifying several of these options, many different problems can be run concurrently.

There is a problem counter built into ATR which is automatically incremented by one every time an *EXC command is encountered; however, each of these problems can be assigned a title by using the *TITLE command. The problem counter is reset to one following a *STOP command.

The primary output mechanism is embodied in the *PRINT and *WRITE commands, by which the fully detailed angle-energy output of ATR response characteristics can be obtained. It is also possible to limit the detail of the output to obtain an integral radiation response environment. Table 29 contains the possible ATR response options corresponding to options in the *PRINT and *WRITE commands and Table 30 further details the units associated with the responses. Of course, the output is labeled with the proper physical units for all of the responses.

The read and print logical unit definitions correspond to the industry standards. The built-in logical unit values are:

    5: input unit for command inputs
    6: output unit associated with *PRINT command
    8: output unit associated with *WRITE command.

The *WRITE command is used to place the results from ATR on an external storage device such as disk or magnetic tape for further analysis.

Dose at several geometry coordinates can be obtained simply by the use of the *DOSE command and in this case no other output command is necessary. There are eight sets of built-in dose responses for neutrons and four for photons, see Section 4 for

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TABLE 29. ATR RESPONSE OPTIONS

Response Index (i)	Neutron Response	Gamma Ray and X-Ray Responses
0	Summary of Responses	Summary of Responses
1	Number Fluence	Number Fluence
2	Number Current	Number Current
3	Energy Fluence	Energy Fluence
4	Energy Current	Energy Current
5	Henderson Tissue	Henderson Tissue
6	Synder-Neufeld	Concrete/Gold (X-ray)
7	Tissue Kerma	Air
8	Mid-Phantom	Silicon
9	Concrete	Not Used
10	Air	Not Used
11	Non-Ionizing Silicon	Not Used
12	Ionizing Silicon	Not Used
13	External Flux Weight	External Flux Weight
14	Not Used	Not Used
15*	Results from *DOSE Command	Results from *DOSE Command
16*	Results from *CONSTRAINT Command	Results from *CONSTRAINT Command

* To be used with *WRITE command only.

TABLE 30. RESPONSE DEFINITIONS AND UNITS

		Neutrons and Gamma Rays	X-Rays
Number Fluence	$\phi(r,E,\mu)$	particles/MeV·cm^2·steradian	particles/keV-cm^2-steradian
Number Current	$\mu\,\phi(r,E,\mu)$	particles/MeV·cm^2·steradian	particles/keV-cm^2-steradian
Energy Fluence	$E\,\phi(r,E,\mu)$	particle-MeV/MeV·cm^2·steradian	particle-cal/keV-cm^2-steradian
Energy Current	$E\mu\,\phi(r,E,\mu)$	particle-MeV/MeV·cm^2·steradian	particle-cal/keV-cm^2-steradian
Dose	$R(E)\,\phi(r,E,\mu)$	rads/MeV·steradian	rads/keV-steradian

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values of the response functions. In the event that the standard dose responses are not adequate, the user can specify responses of his own by the *FLUXWT command. Up to five sets of these output commands can be specified: one each for neutrons, secondary gamma rays, prompt gamma rays, combined secondary and prompt gamma rays, and X-rays. These responses are stored until deleted by the *DEL command or *STOP command or the termination of the program by the *FIN command.

Isodose contour values of any of the integrated responses can be obtained by the use of the *CONSTRAINT command which calculates the geometry configuration corresponding to a predetermined response level for given values of two other geometry coordinates.

The output of differential results or results integrated over only one of the independent variables can be displayed according to user-desired energy or angle boundaries by using the *E-REGRP or *A-REGRP commands respectively. The output will be regrouped from the internal energy and/or angle representation to the user specified boundaries. These two commands can be used individually or together. If a full angle-energy distribution is specified by the output commands, then a two-dimensional regroup will take place before the results are displayed. The angle and/or energy spectrum is regrouped over the ranges specified by these commands.

It should be emphasized that for any given ATR problem any and all of the output commands can be specified for any and all of the particles provided that the set of commands is consistent and that the proper source spectrum has been specified. An ATR problem in this sense includes all cumulative specifications prior to an *EXC command. One example of inconsistent output definition is to specify *E-REGRP or *A-REGRP without specifying a non-zero response index for either a *PRINT or *WRITE command.

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6.4   SPECIFIC OUTPUT COMMANDS

*TITLE n

n = up to 74 characters used as a problem descriptor title to
    identify the output. The title will remain in effect until
    a new title is entered or a *STOP command is encountered.

$*PRINT/z/(i_1 i_2 \ldots)$

z   = N, G, X, NG, GG, T representing neutrons, prompt
                  gamma rays, x-rays, secondary gamma rays, com-
                  bined prompt and secondary gamma rays and total
                  response respectively. The GG option sums the
                  quantities obtained for the secondary gamma rays,
                  prompt gamma rays and fission product gamma rays.
                  The T option is used in conjunction with the PRINT,
                  DOSE and CONSTRAINT commands to obtain the total
                  neutron plus total gamma ray results for the fol-
                  lowing doses:

                       Henderson Tissue
                       Concrete
                       Air
                       Silicon (ionizing)

                  The resulting reponse value, of course, will depend
                  on which source defintions are present. That is,
                  if both neutron and prompt gamma ray source spectra
                  are specified than all three values of neutron,
                  secondary gamma ray and prompt gamma ray results
                  are accumulated. If only the neutron source spec-
                  trum is specified, then the results for neutron and
                  secondary gamma ray radiation are accumulated. Table
                  31 details the possible input and output configurations.

i_1, i_2, etc. = integer values between 0 and 13 separated by
                  blanks corresponding to the response options
                  listed in Table 29. Note that options 9 through
                  12 are used only for neutrons. If a minus sign
                  ("-") precedes the number, the fully differential
                  angle-energy display of the output will be sup-
                  pressed and only output detailing the response as
                  a function of angle (integrated over energy) and
                  as a function of energy (integrated over angle) is
                  displayed accompanied by the cumulative total re-
                  sponse. The minus sign makes no sense preceding
                  the 0 option which is the summary print option

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TABLE 31. OUTPUT POSSIBILITIES AS A FUNCTION
OF SOURCE SPECIFICATION

Dose or Constraint Activated By	Required Source Specifications	Effective Output
N	N	N
G	G	G
X	X	X
FP	FP	FP
NG	N	NG
GG	N,G	NG+G
GG	N,G,FP	NG+G+FP
GG	N,FP	NG+FP
GG	G,FP	G+FP
T	N	N+NG
T	N,G	N+NG+G
T	N,FP	N+NG+FP
T	N,G,FP	N+NG+G+FP

Key:
N: Neutron
G: Prompt Gamma Ray
X: X-Ray
FP: Fission Product Gamma Ray
NG: Secondary Gamma Ray
GG: Combined Gamma Ray
T: Total

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which includes total integrated quantities of Henderson tissue dose, ionizing silicon dose, fluences, currents, external flux weight and average energy.

The summary printout also includes forward and backward quantities which are obtained by integrating over the forward angles (i.e., $\mu > 0$) and backward angles (i.e., $\mu < 0$) respectively. Any number of appropriate integer options may be included and their order is immaterial. Also, print option commands are cumulative through successive *EXC commands unless turned off by using the *DEL command. Fission product dose output <u>cannot</u> be obtained using the PRINT command--the <u>DOSE</u> and CONSTRAINT command must be used.

<u>Examples</u>:

1.   *PRINT/N/(0 -1 4 -9 13)

      which specifies the output for neutrons of the summary as well as following responses: number fluence (omit full energy-angle detail), energy current (with full energy-angle detail), concrete dose (omit full detail) and external flux weight (with full detail).

2.   *PRINT/GG/(0 -2 6)

      which specifies the summary of res   , number current (omit full detail) and conc   dose response for combined secondary and prompt gamma rays.

3.   *PRINT/X/(6)

      which specifies the full detailed printout of the gold dose response for X-rays.

4.   *PRINT/T/(0)

      which specifies the summary of the total responses from all specified sources.

$*WRITE/z/(i_1 \ i_2 \ ...)$

This command is analogous to the *PRINT command in terms of option interpretation with the exception that options 15 and 16 must be specified if the results from the *DOSE or *CONSTRAINT commands, respectively, are to be placed on the external storage device. (Note that option 14 is not used.) Options 15 and 16 are not used with the *PRINT command because the *DOSE and *CONSTRAINT commands automatically turn on the corresponding print options.

The consequences of the *WRITE options are precisely the same as those of the *PRINT options except that they are output to a different output device.

Examples:

1.   WRITE/NG/(2   5   8)

     which specifies the detailed output of number current, Henderson tissue dose and silicon dose for secondary gamma rays to the external storage device.

2.   WRITE/G/(6   15   16)

     which is the specification of detailed output of con- crete dose, the results from the *DOSE command and the results from the *CONSTRAINT command for prompt gamma rays to the external storage device.

$*DOSE/z/$

z = N, G, X, NG, GG, T, FP

This command automatically prints integrated dose values as a function of the running coordinate specified by the geom- etry setup. There are eight different dose responses for neutrons and four different dose responses for photons.

The FP command is used to activate the fission product model. The summary and other print options <u>cannot</u> activate

the fission product model because there is only dose information in the model and also because it does not contain any angular dependence. Table 31 details the possible output configurations for the DOSE and CONSTRAINT commands as a function of source specification. This table illustrates which sources must be defined in order to get the effective output when the "particle" definition construction is used. For example, if the command *DOSE/GG/ is specified for the output and neutron, prompt gamma ray and fission product sources are specified, then the output will be the sum of secondary gamma ray plus prompt gamma ray plus fission product gamma ray radiation.

Examples:

1.   *DOSE/N/

which specifies the dose vs. running geometry coordinate for neutrons.

2.   *DOSE/X/

which specifies the dose vs. running geometry coordinate for X-rays.

3.   *DOSE/FP/

which specifies the fission product dose at the running geometry coordinates.

4.   *DOSE/T/

specifies that the total dose from all specified sources be determined for the running geometry coordinate.

*CONSTRAINT/z/(xx i value), units

z   = same as for DOSE.

xx   = RS.

i   = is the response designator (only options 1-13 are meaningful).

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value = constant response value of (non $4\pi R^2$) fluence, current, dose or external flux weight for which the constraint geometry is evaluated. The value cannot be a $4\pi R^2$ response, since this may be double valued.

units = same as the standard distance unit definitions. This unit definition designates the output units of the geometry distance coordinates. If no units are specified, the default is meters.

This command combined with two geometry coordinate specifications calculates the value of coordinate RS which corresponds to the predetermined response level given by the value. Of course, care must be taken to specify a consistent and valid set of geometry configurations.

Examples:

1. *CONSTRAINT/N/(RS 13 3+15), KFT

   This combined with two commands (Cxx) of constraint geometry coordinates specifies isodose values of the slant range (RS) for neutrons where the response value is $3 \cdot 10^{15}$ of the external flux weight. The distance values will be output in units of kilofeet.

2. *CONSTRAINT/GG/(RS 1 5+6), MILE

   which specifies the constraint calculation of the slant range on the number fluence value of $5 \cdot 10^6$ for combined secondary and prompt gamma rays. The distance values will be displayed in units of miles on the output.

3. *CONSTRAINT/X/(RS 6 2+12)

   which specifies the constraint calculation for x-rays on the slant range, the constant response value of the gold dose is $2 \cdot 10^{12}$ and the distance coordinates will be output in meters which is the default when the units are not specified.

4. *CONSTRAINT/FP/(RS 5 1E+5)

   specifies that the distance RS in meters corresponding to a fission product dose of 10^5 rads is to be determined.

*FLUXWT/z/,units, values

z = N, G, X, NG (same as G).

units = arbitrary, user specified units, up to 16 characters (not including a comma) that will appear on the output. If no units are specified then the commas should not appear.

values = flux weight values to be used for weighting the ATR energy spectrum and must correspond to the internal energy structure (low to high energy values) and contain 22 neutron, 18 gamma ray and 20 X-ray numbers depending on x.

The flux weight values will remain stored by ATR until the termination of the run or until a *STOP command is encountered.

Examples:

1. *FLUXWT/NG/,CM**2 ERGS/GRAM, 5.9-8 1.2-8
   8.-9 1.2-8 1.7-8 2.4-8 3.3-8 4.1-8 5-8 6.15-8
   7.15-8 8.4-8 9.8-8 1.2-7 1.5-7 1.8-7 2.2-7 2.65-7

   this command specifies external flux weights for secondary gamma rays corresponding to the internal 18 detector energy groups in order of low to high energy values.

2. *FLUXWT/N/, RADS SIL. KERMA, 0 0

   0 0 0 0 0 0 0 2-11 3.1-11 3.4-11 4.2-11
   4.7-11 4.8-11 4.8-11 5.1-11 5.5-11 6.6-11 6.4-11
   6.6-11 7.5-11

   which specifies external flux weights for neutrons, the 22 values correspond to the internal neutron detector energy structure, the 9 low energy values being zero.

*E-REGRP/z/, units, values

z = N, G, X, NG, GG.

units = MEV, KEV. The default unit is MEV for neutrons and prompt gamma rays and KEV for X-rays.

values = energy <u>boundary</u> <u>values</u> (low to high) which will be
used to <u>regroup</u> output results.

In versions 1 and 2 or ATR, problems have been encountered
with the regroup function. Version 3 incorporated a new method.
The basic problem can be stated by the following. Given a set of
$\{f(x_i)\}$ defined on the set $\{x_i\}$, one needs a mechanism to cal-
culate the set $\{f(x_j)\}$ corresponding to a given set $\{x_j\}$ which
is different from $\{x_i\}$. In actual practice some of the $\{x_i\}$
may be the same as some of the $\{x_j\}$.

These data may be in either histogram or point form and
the regroup mechanism must account for both types of data. The
approach utilized is based on procedures that fit a third order
polynomial spline function based on five adjacent points. The
consequence of the spline is that the derivatives are also
matched at the transition points.

The form for the polynomial is:

$$y = p_0 + p_1(x-x_1) + p_2(x-x_1)^2 + p_3(x-x_1)^3$$

where

$$p_0 = y_1$$

$$p_1 = t_1$$

$$p_2 = \{3(y_2-y_1)/(x_2-x_1) - 2t_1 - t_2\}/(x_2-x_1)$$

$$p_3 = \{t_1 + t_2 - 2(y_2-y_1)/(x_2-x_1)\}/(x_2-x_1)^2 \quad .$$

In addition, the slope t at the middle point is defined in
terms of the slopes m_i at the corresponding points:

$$t = (|m_4-m_3| \, m_2 + |m_2-m_1|m_3)/(|m_4-m_3| + |m_2-m_1|) \quad .$$

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This spline interpolation scheme is applied to the cumulative integral and the interpolated values are differentiated.

Examples:

1.   *E-REGRP/NG/,MEV, .1 .5 . 2 3 5 10

    which specifies the six (seven boundary values) groups to which the output will be regrouped for secondary gamma rays. The unit definition is superfluous since MeV is the default unit for this case.

2.   *E-REGRP/X/10 45 70 95 150 240 300

    which specifies the energy boundaries in keV (the default unit) to which the output will be regrouped for X-rays.

*A-REGRP/z/, units, values

z   = N, G, X, NG, GG

units = DEG (degrees), RAD (radians), COS (cosine). Default units are degrees.

values = angle boundary values (low to high cosine values) which will be used to regroup output results. An odd number of values must be input.

Since the natural unit for the angle dependent data in ATR is the cosine of the angle, the user must exercise some care in the treatment of this command. The default unit is degrees and the value range is 0-180 degrees. However, this means that if the cosine values (ranging from -1 to +1) must be entered low to high then the degree values must be entered high to low. Also since degrees and radians are directly related, if radians are used for the units then the values must occur high to low.

Examples:

1. *A-REGRP/N/,COS, -1 -.5 0 .25 .5 .75 1.

    which specifies the angular regroup of neutron out-
    put to the given cosine values.

2. *A-REGRP/X/,DEG, 180 120 90 60 45 1C 0

    which specifies the angular regroup of x-ray output
    in units of degrees although the unit definition is
    not necessary in this case.

6.5 EXECUTION

Several commands in ATR are concerned with the flow of
control of the execution. Many ATR commands fill corresponding
buffer regions or set appropriate flags, and their order is
immaterial. However, commands described in this section take
effect immediately after being entered.

When the *EXC command is encountered, ATR executes all
concurrent problems and displays the results.

The *DEL command deletes selected input buffers, i.e.,
it clears the effects of certain previous commands or group
of commands.

The *STOP command nullifies all previous commands and
clears the internal flags; it would normally follow an *EXC.

*EXC, 4PIRSQ

This command causes the execution of the concurrent ATR
problems and the display of the results. If the comma appears
after the *EXC then the resulting values will be multiplied
by $4\pi R^2$ where R is the slant range in centimeters.

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<u>*DEL command(s)</u>

command(s) = one or more of the following list:

     1. GEOM
     2. DOSE
     3. CONSTRAINT
     4. E-REGRP
     5. A-REGRP
     6. PRINT
     7. WRITE
     8. FP

Several deletions may be effected at once with a single *DEL specification, provided that the corresponding command words are separated by blanks. There is no command for source spectrum deletion since the effects of a source can be nullified by deleting the corresponding print options. In any case, the *STOP command also <u>resets all</u> specifications, even those relating to source, including the ones that can be selectively reset by *DEL.

The special command (GEOM) can be used to erase the set of buffers associated with the geometry coordinates. When the user specifies a set of coordinates, the components already specified can be changed. When it is desirable to define the geometry with a different set of components, the *DEL GEOM command should be used and the complete geometry specified.

    <u>Examples</u>:

    1. *DEL DOSE CONSTRAINT FP

       this command deletes the effects of the dose and con-
       straint commands previously entered as well as those
       specifying the fission product source.

    2. *DEL GEOM A-REGRP E-REGRP

       this command deletes the previously defined geometry
       configuration as well as the angle and energy regroup
       boundary values.

*STOP

This command clears all flags and internal buffer areas set up by previous specifications. ATR is initialized and complete problem specification must follow the STOP command.

*FIN

This command terminates the program with a FORTRAN STOP.

7. ATR APPLICATION INFORMATION

The ATR code has been implemented on several different
computers and an attempt has been made to keep the code as
computer independent as possible. The code is written in
FORTRAN IV with Hollerith constants kept at a maximum of four
characters to the computer word. ATR versions have run on
the following computers: Univac 1108, CDC 6600, CDC 7600,
DEC System 10, GE 635, IBM 360, IBM 370. The code can be run
in a timesharing interactive mode as well as in a batch oriented
environment.

Version 4 of the ATR code takes about 62K words of core on
the DEC System 10. The execution time is typically one second
or less for most ATR problems.

7.1 COMMON ERRORS

Most user errors on input occur in the specification of
the source. The convention is that energy values and corre-
sponding source values are to be entered from low energy to
high energy. Also, if point values of the source are specified,
then the number of energy values must match the number of source
values. Similarly, if a histogram source spectrum is specified
in a group structure other than that used in ATR, then the
number of energy values must be one more than the number of
source values. If source values are entered corresponding to
the internal energy structure then the energy values need not
be specified but only 18 values are required for either neutron
and/or gamma ray sources.

When multiple problems are run and only the yield com-
ponent of the source is changed from one problem to the next,
then at least once (preferably for the first problem) a

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normalization should be entered so that the code will normalize the source to the normalization value for every problem before multiplying by the yield.

A common geometry error occurs if an impossible configuration is specified. For example, the following set of geometry specifications:

```
*HS,KM,2
*HT,KM,1
*RS 500
```

is in error since the slant range value is too short to reach from the source to the target.

The following describes the error diagnostics that are possible from ATR Version 4.

Error messages produced by ATR are of two types:

1. errors in the form of commands

2. errors in the content of commands

The first is associated with the input phase and the second with the execution and output phase of the code. The next two sections will elaborate on the error messages and corresponding probable causes. Error messages are always preceded by two asterisks.

7.2   INPUT PHASE ERROR MESSAGES

1.   **UNRECOGNIZABLE CONTROL COMMAND <input characters>

Which means that the command just entered is invalid. The <input characters> field displays the first ten command characters as interpreted by ATR.

2.   **MISSPELLED CONTROL COMMAND--INTERPRETED TO BE <ATR Command>

In certain instances ATR "forgives" the misspelling of a command and displays the form of the command as interpreted by ATR. Further processing of the command then takes place beginning with the first blank or comma character, whichever occurs first.

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3. **OPTION <Option numbers> NOT IMPLEMENTED

    This signals that the command was recognized but the option corresponding to the command is not implemented in this version. This error message should not be seen in Version 4.

4. **ILLEGAL SOURCE SPEC

    This covers a multitude of errors relating to the form of the *z-SOURCE(i) command, such as parenthesis left off or in wrong place, or the value of i does not correspond to permissible values.

5. **ILLEGAL UNITS SPEC

    Which reports errors encountered relative to the ",units," specification for source related commands.

6. **ILLEGAL NORM SPEC -- ASSUME 1.0

    Which will appear if an illegal normalization command is specified. This error need not be corrected if the value of 1.0 is an acceptable source normalization.

7. **ILLEGAL YIELD SPEC -- ASSUME 1.0

    Which is very similar to (6) but applies to source yield.

8. **PARTICLE DEFINITION ERROR

    This will occur if the particle definition of an output command is in error.

9. **UNIT DEFINITION ERROR

    Which reports errors encountered relative to the ",units," specification for non-source related commands. Further processing of the command begins with the first blank or comma character whichever occurs first.

10. **VALUE PARAMETER ERROR

    Which means that a value entered as part of the "value(s)" field does not correspond to acceptable value definition. This error message does not cover all possible value errors.

11. **OVERFLOW OF NUMBER OF VALUES

This signals that the number of values entered by
the particular command exceeds the number of values
allowed (for most commands this number is 50).

12. **VALUE SEQUENCE ERROR

Which usually means that the "low-to-high" condition
was violated in the "values" field; however, only
the first two values are examined.

13. **ILLEGAL OUTPUT SPEC

Which means that an error was detected concerning
the processing of a *PRINT or *WRITE command.

14. **CONSTRAINT DEFINITION ERROR

Which means that the form of a *CONSTRAINT command
is in error.

15. **COMMAND DOES NOT BELONG - <command>

Which means that the argument of a *DEL command is
recognized as an ATR command but is improper as the
argument of the *DEL command.

7.3   EXECUTION AND OUTPUT PHASE ERROR MESSAGES

1. **ERROR IN <particle> SOURCE SPEC

Which means that the source specification correspond-
ing to the <particle> is found to be in error. Usually
this is due to regroup errors in the source specifica-
tion or non-corresponding number of source and energy
values or the wrong choice of parameters in the
*z-SOURCE(i) command.

2. **NO SOURCE SPEC

This error message usually follows those of type (1)
above and signals that all of the source specifications
are found in error. This message is usually followed
by: **EXECUTION ABANDONED.

3. **GEOMETRY CONSISTENCY ERROR

This means that the specified geometry coordinates specified are inconsistent, i.e., the three coordinates chosen by the user do not specify a consistent geometry.

4. **GEOMETRY DEFINITION ERROR

Which means that the given values of the geometry coordinates specified are in some way in error, e.g., specifying a longer horizontal range than slant range.

5. **CONSTRAINT FLUX WEIGHT DESIGNATOR ERROR

Which means that the response designator index specified by the *CONSTRAINT command is in error.

6. **CONSTRAINT EVALUATION ERROR i

Which means that the evaluation of the constraint problem for the given constraint geometry configuration cannot be obtained because of one of the following reasons depending on the value of i:

1. geometry consistency error
2. geometry evaluation error
3. number of initial iterations is greater than 10
4. number of gm/cm^2 is greater than 1050 during the iteration process
5. number of gm/cm^2 is less than 10^{-20} during the iteration process
6. no convergence after 20 iterations

7. **ABOVE CONSTRAINT RESULT MAY BE IN ERROR

Which refers to the line of the geometry configuration just above this error message and it indicates that the computed slant range is less than the built in acceptable value.

8. **REGROUP ERROR

Which signals that some kind of error was encountered when regrouping the input source spectrum or that an error was encountered on regrouping output results. One possible source of error is embedded source spectrum values which are zero.

9.   **EXECUTION ABANDONED

Which usually means that there was not one acceptable
source spectrum specification.

10.   **EXECUTION COMPLETED

This message appears whenever ATR has completed its
intended purpose and is ready for more input commands.
It is not an indication of an error.

8. REFERENCES

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APPENDIX A

FISSION PRODUCT GAMMA RAY DOSE COMPARISONS

The engineering model utilized in ATR to predict the fission product dose is based on empirical equations which provide a reasonable fit to experimental data from large yield weapons. The parametrized models used in other codes such as IDEA[11] are generally much more complex and are based on detailed phenomenology calculations. To provide a comparison between the two models several calculations have been made.

Figure A-1 shows the fireball rise rate for a 10 KT burst as it is modeled in ATR (independent of height of burst) compared with the burst height dependent data for IDEA. Since the phenomenology used in IDEA (based on the LAMB[20] code from the Air Force Weapons Laboratory) is still undergoing development, the more simplified model is used in ATR. As further data on fireball rise becomes available, the model used in ATR should be reevaluated.

Comparisons of dose values generated by the fission product model in ATR are made with other available data. Figures A-2 to A-4 present comparisons with curves generated by the IDEA code. For these figures the ground level in ATR was placed at 300 meters in order to correspond to the air density at which the IDEA curves were generated. The target height is 1.75 meters. Figures A-5 and A-6 also have the same ground and target parameters and they illustrate the source and fireball rise model sensitivity respectively.

Figures A-7 through A-10 represent other examples of comparisons with IDEA and also TDM which is a code used to calculate tissue dose in air-over-ground geometries.[22] For these comparisons the ground is at zero as is the target height.

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In general these comparisons show that the ATR model represents the fission product component of radiation reasonably well. The areas of serious disagreement with other codes are due to the simple fireball rise model used in ATR since the fission product model is relatively sensitive to the fireball rise rate. The objective of implementing a fission product model in ATR that is very fast, with each problem taking only a fraction of a second, has been met. The limitations must be realized however.
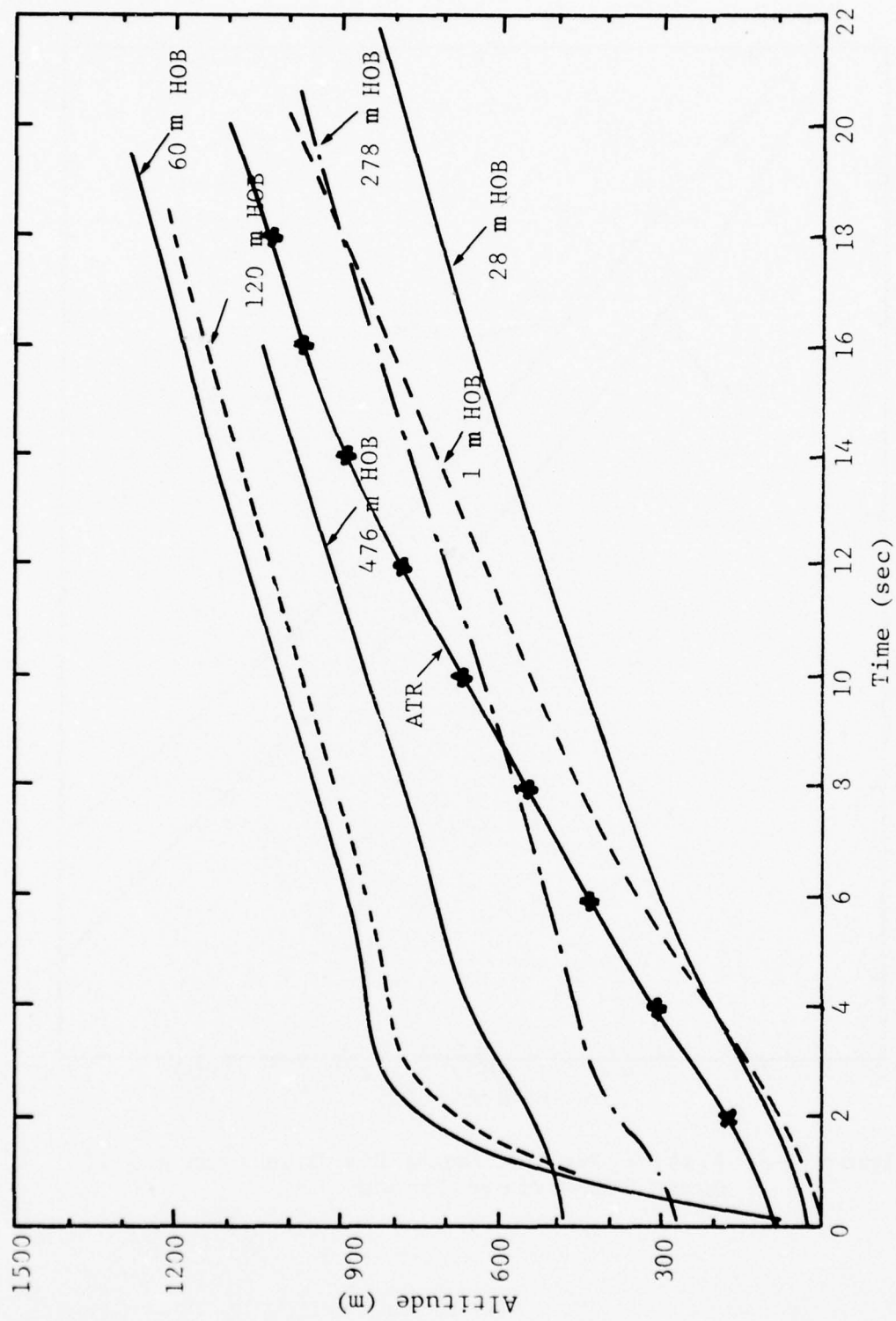
Figure A-1. Fireball Position as a Function of Time for a 10 KT Burst for Several Heights of Burst (HOB)

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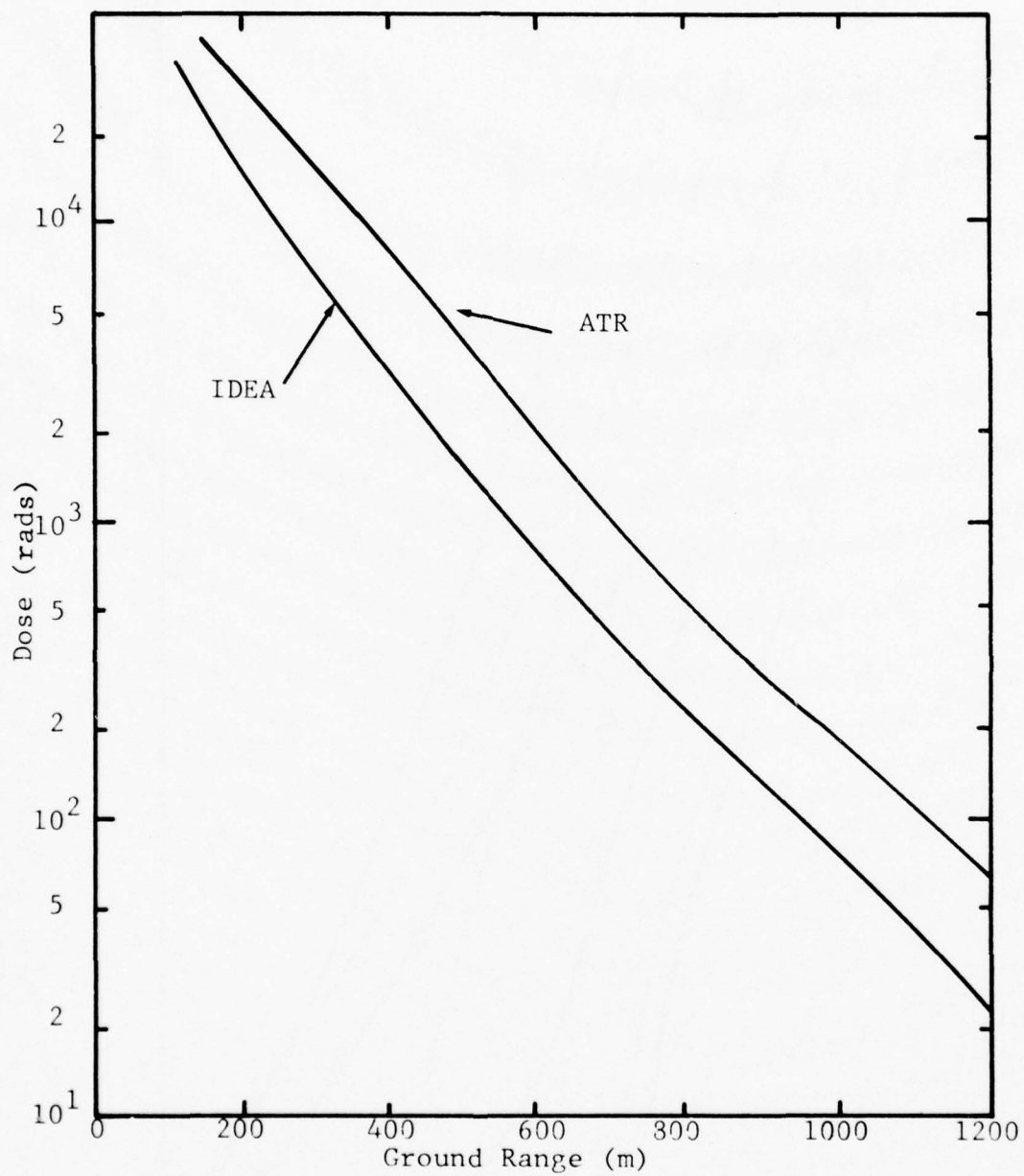
Figure A-2. Fission Product Gamma Ray Dose from a 5 KT
Burst 100 m Above Ground

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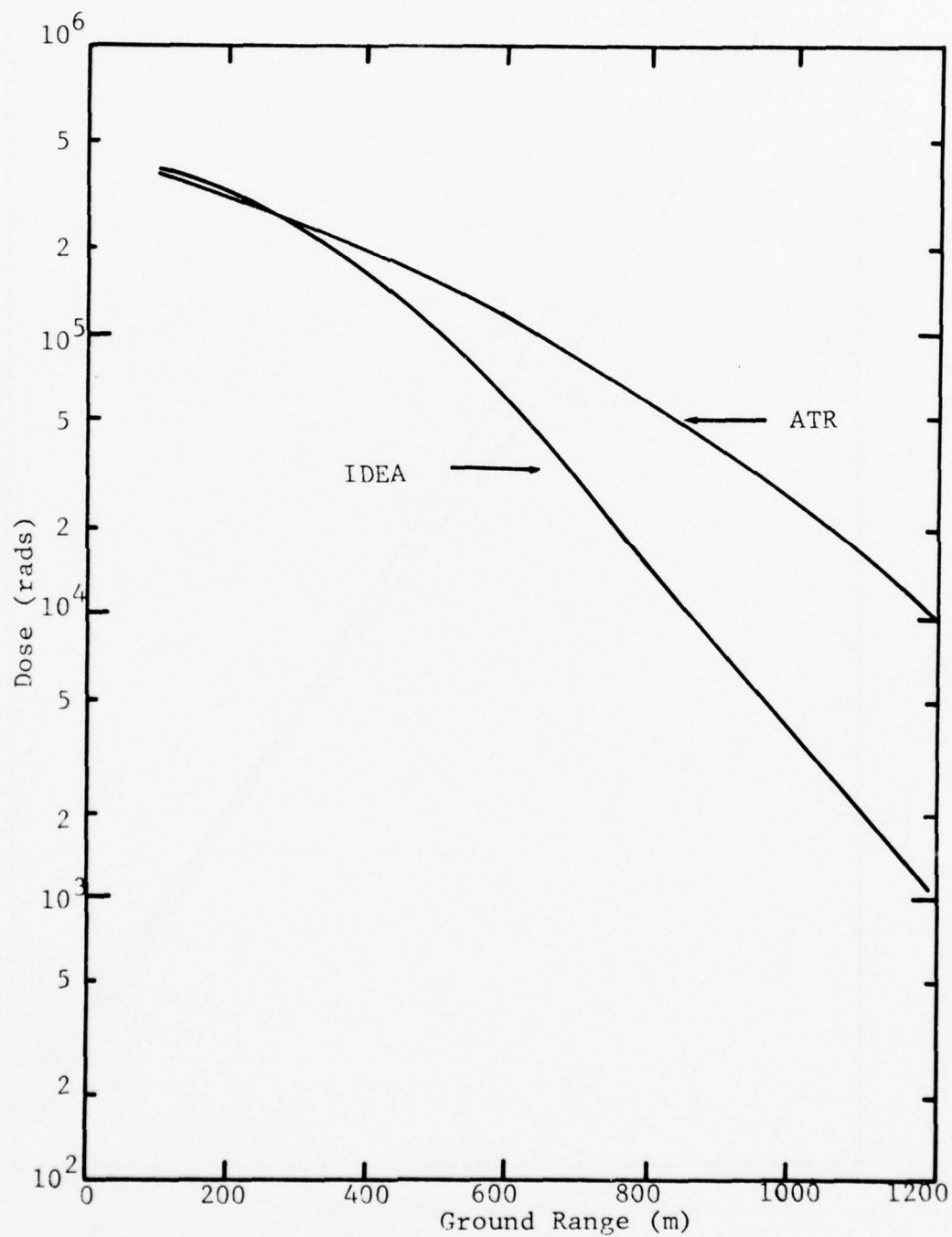
Figure A-3. Fission Product Gamma Ray Dose from a 200 KT Burst 350 m Above Ground

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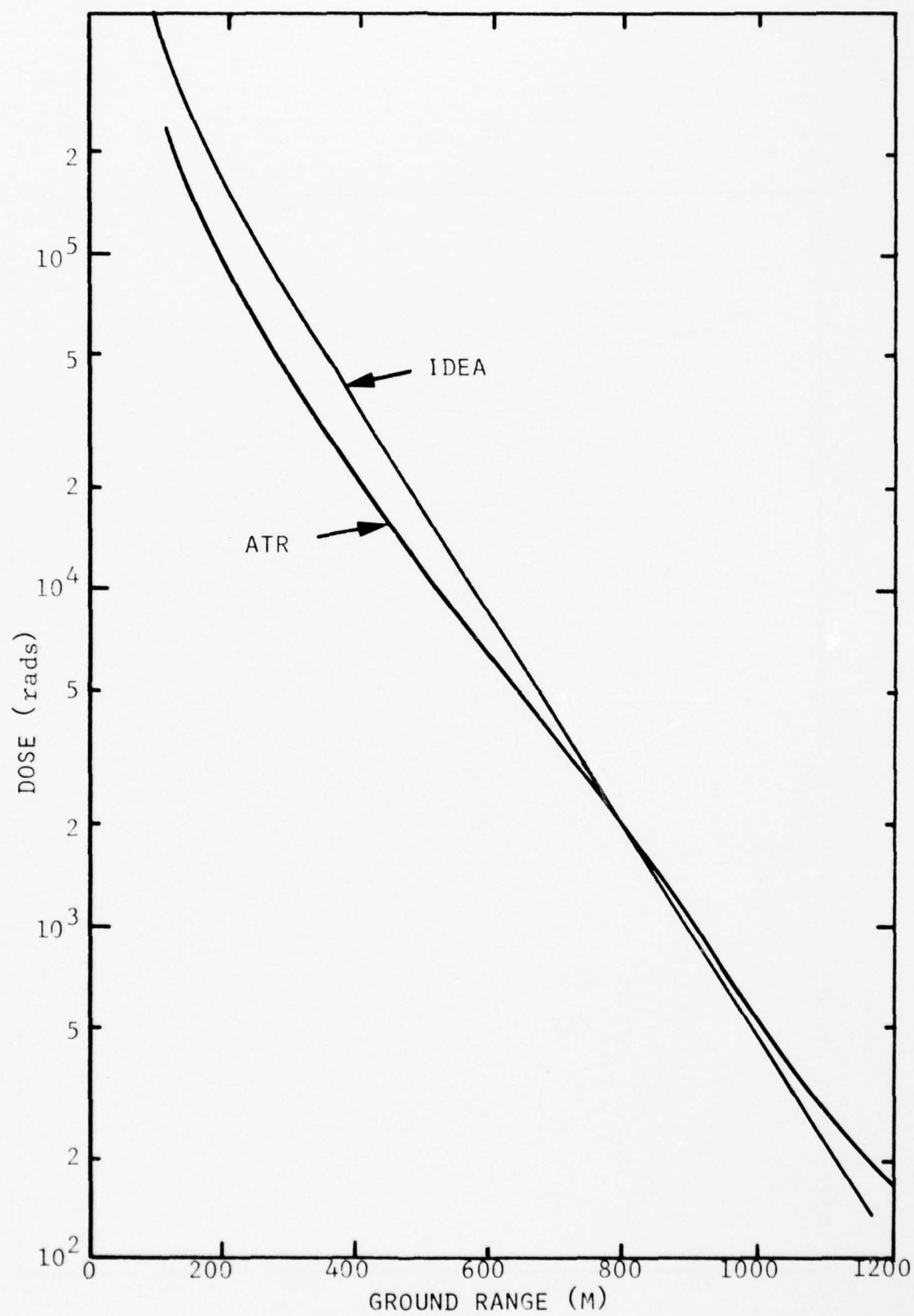
Figure A-4. Comparison of Tissue Dose from Fission Product Gamma Rays for a 10 KT Burst 1 m above Ground

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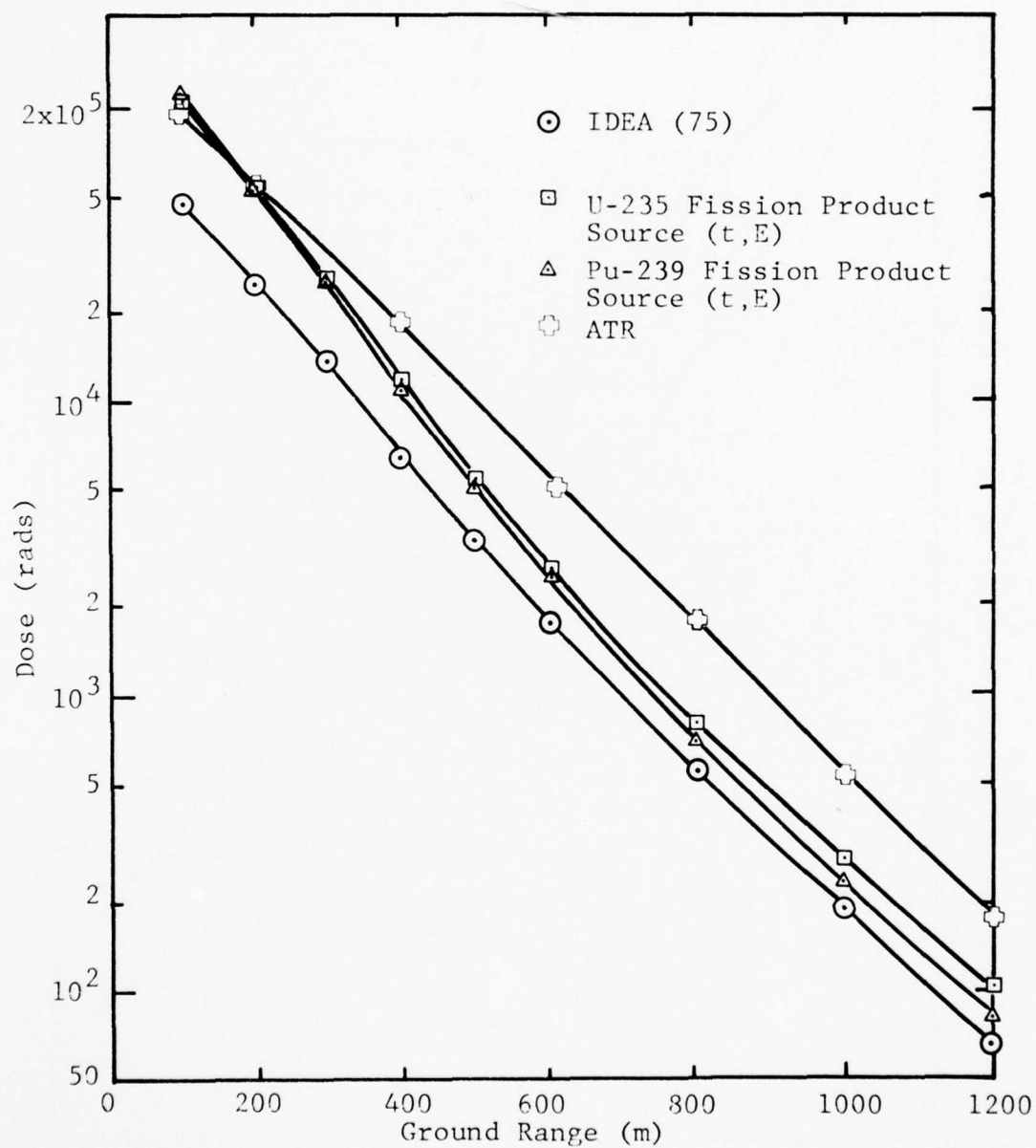
Figure A-5. Calculated Tissue Dose from Three Fission
Product Gamma Ray Source Models vs. ATR for
a 10 KT Burst 129 m Above Ground
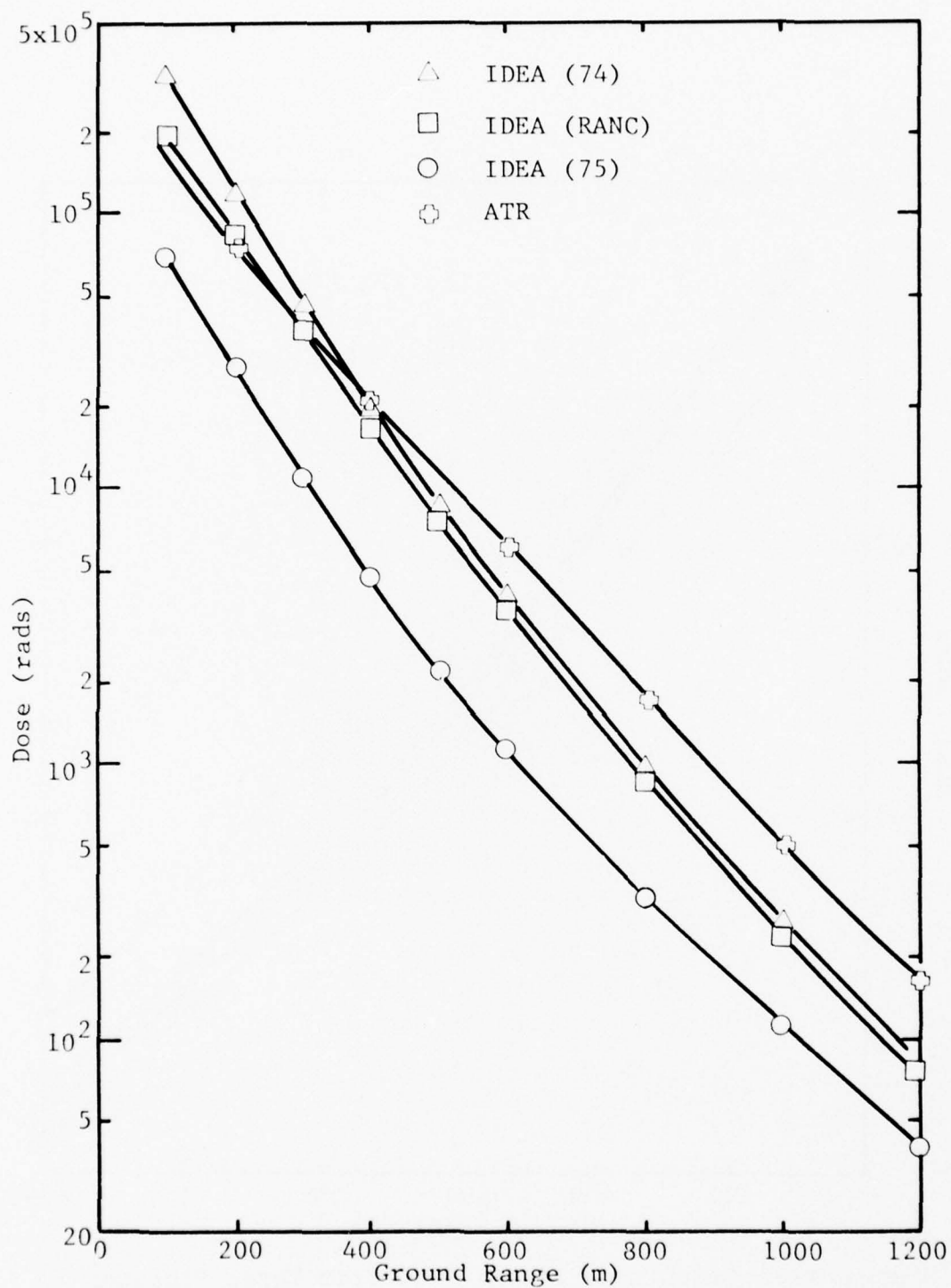
Figure A-6.   Calculated Fission Product Gamma Ray Free Field
Tissue Dose for Different Fireball Rise Models
vs. ATR for a 10 KT Burst 60 m Above Ground.

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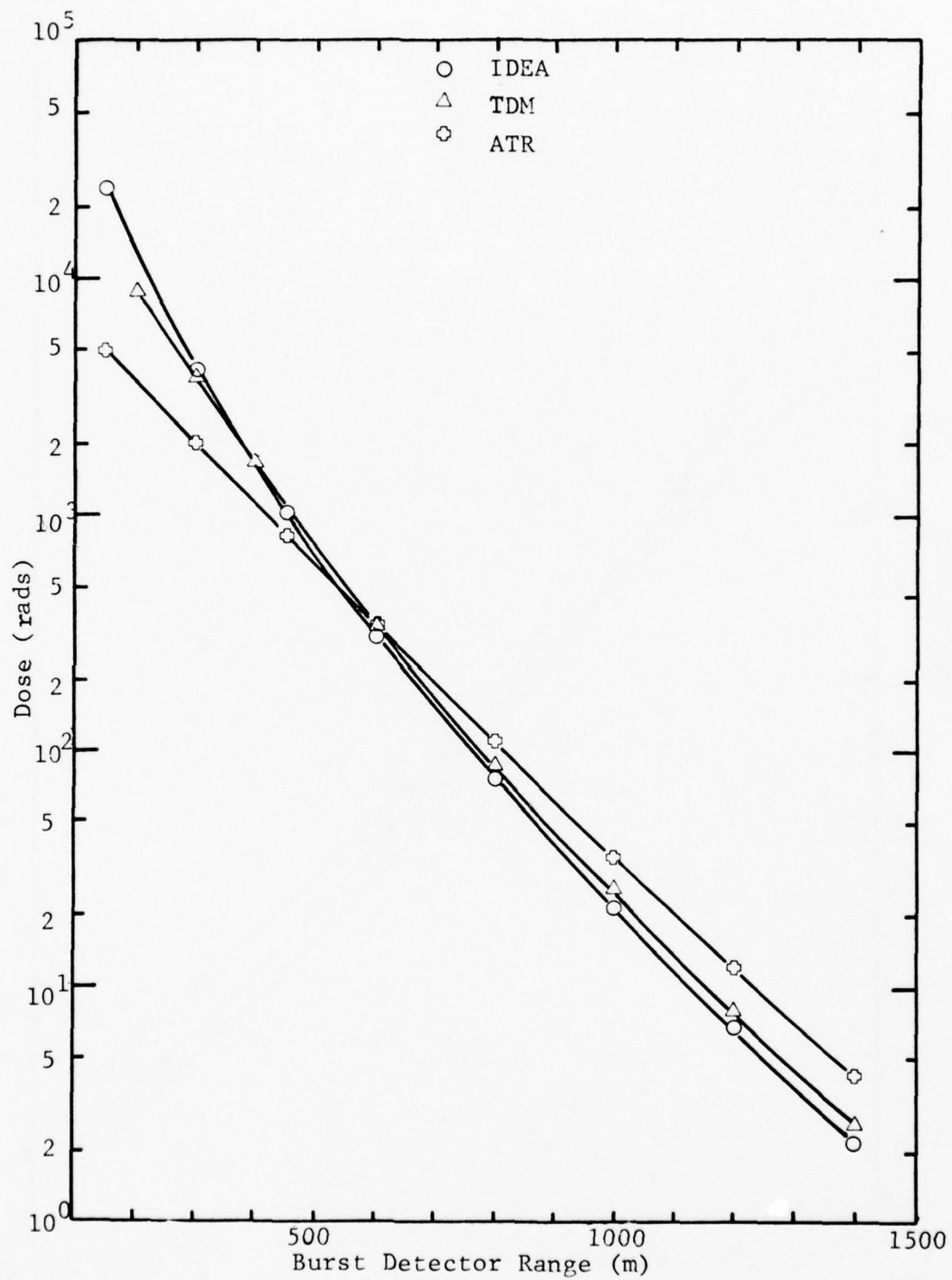
Figure A-7. Fission Product Henderson Tissue Dose
Comparison for a 1 KT Burst at 1 Meter

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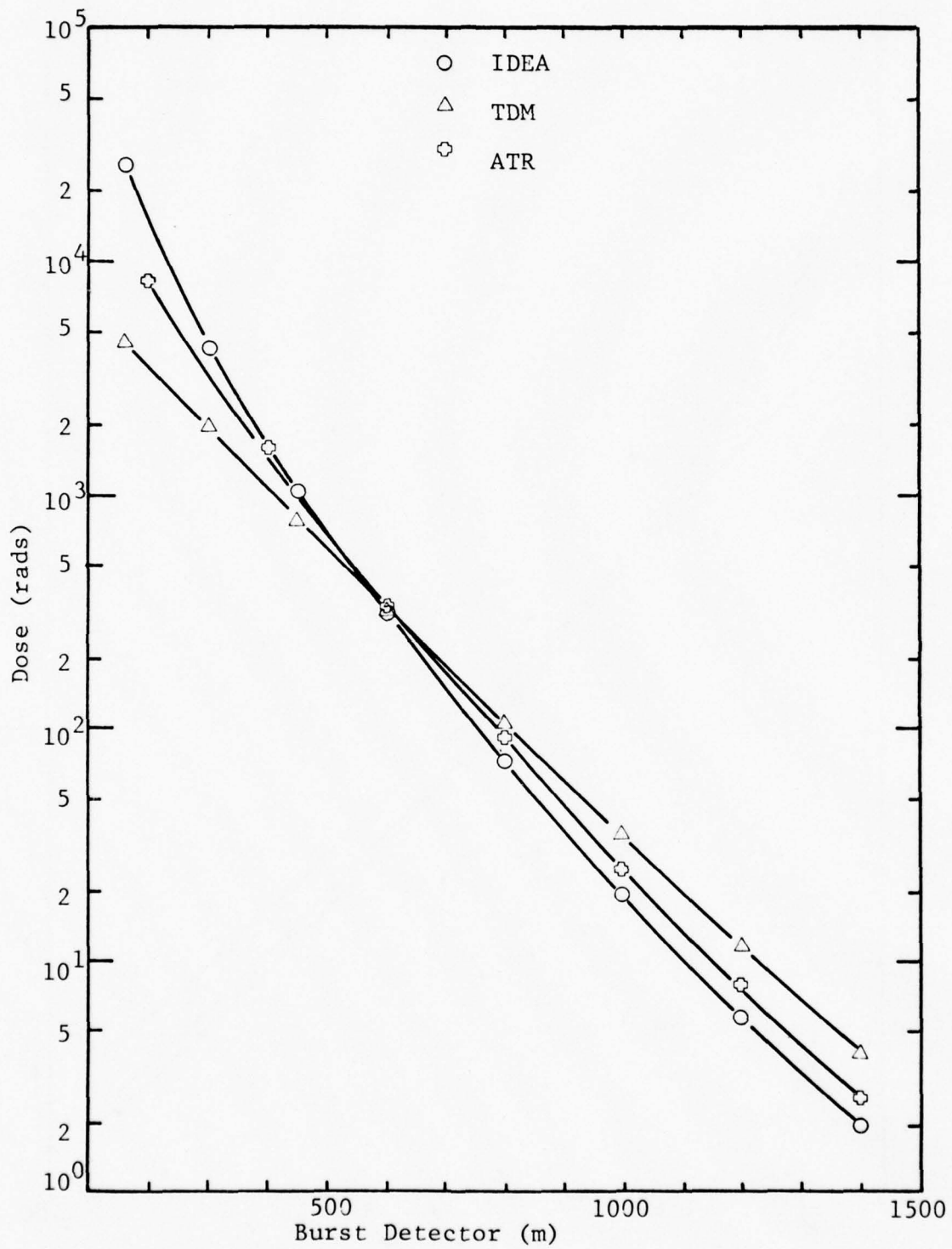
Figure A-8.   Fission Product Henderson Tissue Dose
Comparison for a 1 KT Burst at 60 Meters

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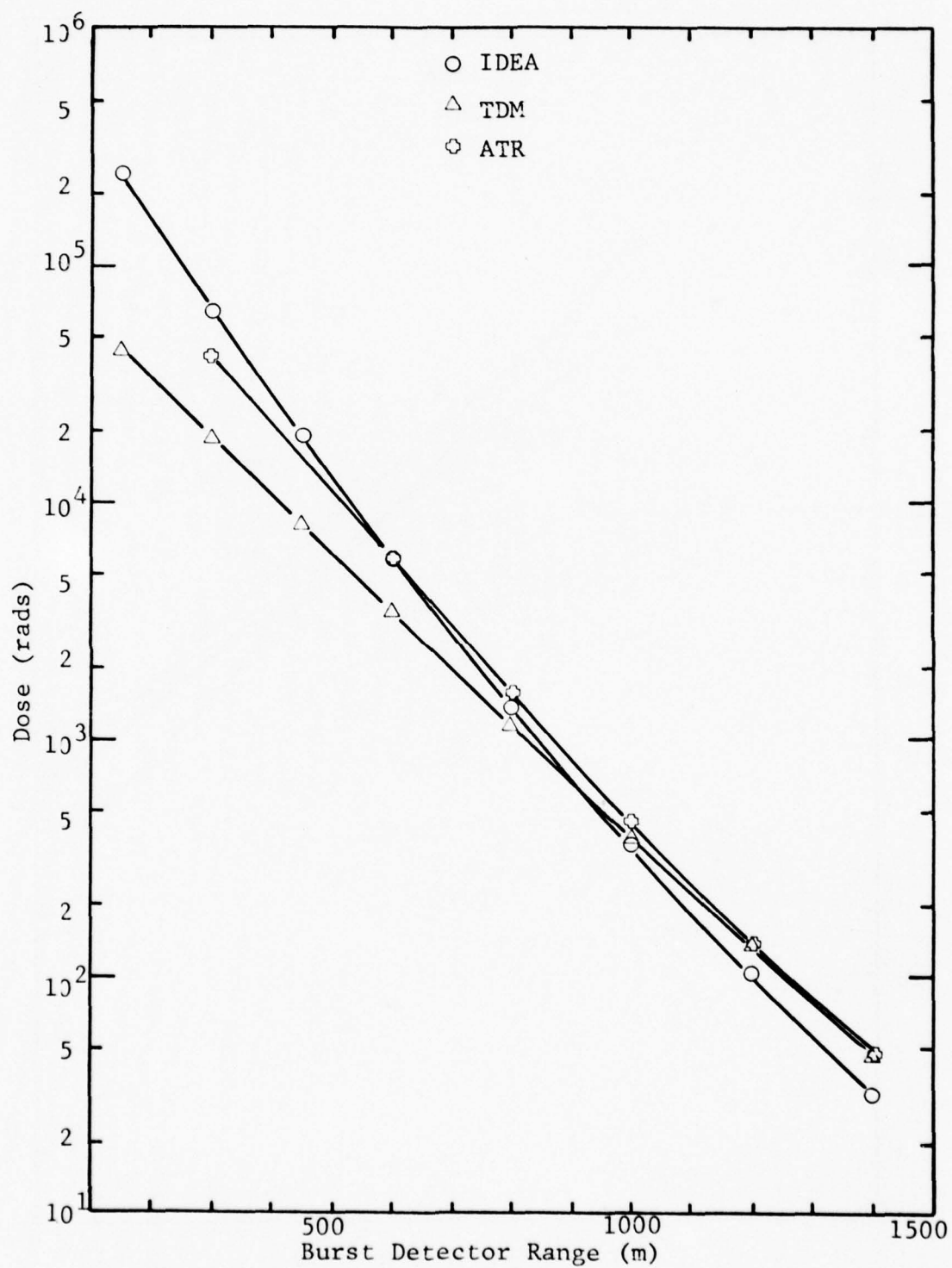
Figure A-9. Fission Product Henderson Tissue Dose Comparison for a 10 KT Burst at 5 Meters

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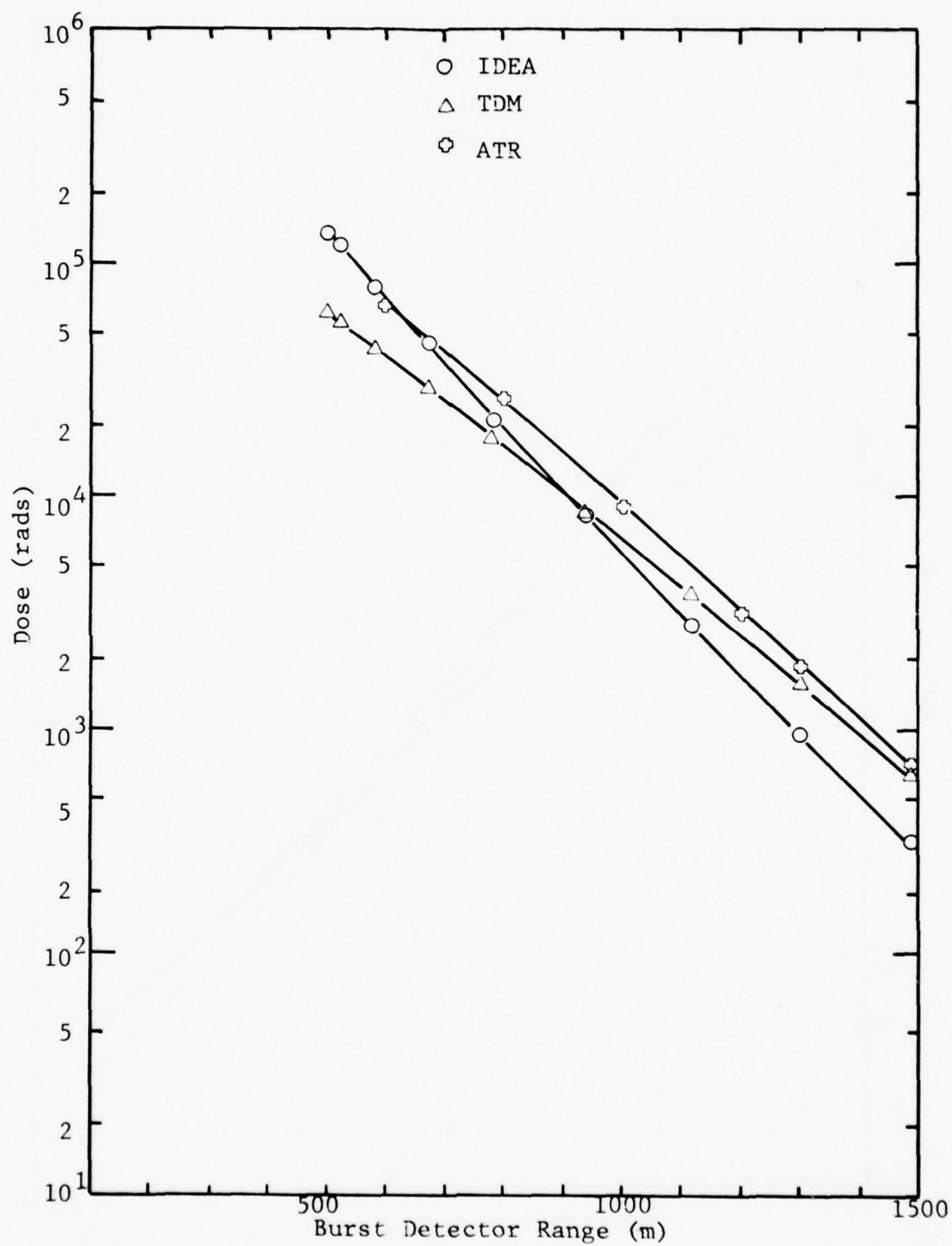
Figure A-10. Fission Product Henderson Tissue Dose Comparison for a 100 KT Burst at 500 Meters

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APPENDIX B

SAMPLE PROBLEMS

The following sample problems are a representative sample of some of the capabilities of ATR Version 4. Each problem was chosen to point out some of the major features of the code. Each problem will be described in some detail, and the input as well as the output is presented. If these problems are run in a single ATR session, then the *STOP command should be used after each problem definition.

Sample Problem 1

This problem presents the use of the fission product part
of ATR. The fission product source has a yield of 10 KT and
a fission fraction of 0.5. The source and target are both at
1 km height and the separation slant range starts at 500 meters
in increments of 100 meters to a maximum of 1000 meters. The
dose is evaluated for each of the geometry configurations
and presented.

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ATR SAMPLE PROBLEM 1 - INPUT

```
*TITLE SAMPLE PROBLEM 1 - ATR VERSION 4.
*FP-Y 10
*FP-F .5
*HS,KE,1
*HT,KE,1
*HS 500(100)1000
*POSE/EPZ
*EXC
```

ATR SAMPLE PROBLEM 1 - OUTPUT

```
ATR PROBLEM NUMBER        1                SAMPLE PROBLEM 1 - ATR VERSION 4.

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

FISSION PRODUCT YIELD=1.00E+01KT,  FISSION FRACTION= 5.00E-01

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ATR PROBLEM NUMBER        1                SAMPLE PROBLEM 1 - ATR VERSION 4.

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  GROUND LEVEL       0.000KM,    0.000GM/CM**2,   0.000KFT,   0.000MILES
*HORIZ. RANGE RH=   0.500KM,   55.583GM/CM**2,   1.640KFT,   0.311MILES
 SLANT RANGE  RS=   0.500KM,   55.583GM/CM**2,   1.640KFT,   0.311MILES
 TARGET ALT.  HT=   1.000KM,  116.741GM/CM**2,   3.281KFT,   0.621MILES
 SOURCE ALT.  HS=   1.000KM,  116.741GM/CM**2,   3.281KFT,   0.621MILES
*SLANT ANGLE  AN=   0.000DEGREES (COS= 1.00000)
         *CALCULATED FROM OTHER COORDINATES


* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

    FISSION PRODUCT  DOSE  VS.  SLANT RANGE        (RADS         )
                DOSE 1=  HENDERSON TISSUE
                DOSE 2=  CONCRETE
                DOSE 3=  AIR
                DOSE 4=  SILICON

SLANT RANGE        DOSE 1   DOSE 2    DOSE 3    DOSE 4
  5.000E+02 M      7.89E+03 1.35E+04 6.85E+03 1.15E+04
  6.000E+02 M      4.19E+03 7.21E+03 3.63E+03 6.12E+03
  7.000E+02 M      2.23E+03 3.79E+03 1.94E+03 3.23E+03
  8.000E+02 M      1.20E+03 2.00E+03 1.05E+03 1.71E+03
  9.000E+02 M      6.61E+02 1.07E+03 5.77E+02 9.24E+02
  1.000E+03 M      3.69E+02 5.86E+02 3.24E+02 5.07E+02


* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
**EXECUTION COMPLETED
```

Sample Problem 2

This problem demonstrates the total dose option of the code. The source spectra used for the calculation are specified as the internal standard option of fission source for both neutrons and prompt gamma rays. The normalization and weapon yield values are not specified, thus the internal default values are used. The geometry configuration is such that the source is at a height of 1 km, the detector is at a height of 2 m and the horizontal range varies from 100 m to 500 m in steps of 100 m. For each one of the geometry configurations the total dose is evaluated and displayed. The total dose in this case is the sum of the dose contributions from neutrons, secondary gamma rays and prompt gamma rays. The dose values are $4\pi R^2$ quantities.

NOTE: If fission product gamma rays were also included, they would dominate the dose, since the source consisted of one neutron and one gamma ray but the fission product results include the number of fissions/KT.

ATR SAMPLE PROBLEM 2 - INPUT

```
*TITLE SAMPLE PROBLEM 2 - ATR VERSION 4.
*G-SOURCE(1)
*N-SOURCE(1)
*HS,XP,1
*HT 2
*RH 100(100)500
*DOSE/T/
*EXC,
```

ATR SAMPLE PROBLEM 2 - OUTPUT

'ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 2 - ATR VERSION 4.

* *

NEUTRON SOURCE   INTERNAL FISSION
NORMALIZATION=1.000E+00 NEUTRON /KT, YIELD=1.000E+00 KT
 TOTAL OUTPUT=1.000E+00 NEUTRON

                    SOURCE SPECTRUM
 ENERGY(MEV)   N   N/MEV   ENERGY(MEV)   N   N/MEV
1.07E-05-2.90E-05 0.00E-01 0.00E-01 2.35E+00-2.46E+00 5.74E-03 5.22E-02
2.90E-05-1.01E-04 0.00E-01 0.00E-01 2.46E+00-3.01E+00 2.87E-02 5.22E-02
1.01E-04-5.83E-04 0.00E-01 0.00E-01 3.01E+00-4.07E+00 5.48E-02 5.17E-02
5.83E-04-3.35E-03 0.00E-01 0.00E-01 4.07E+00-4.97E+00 1.15E-02 1.31E-02
3.35E-03-1.11E-01 2.23E-01 2.07E+00 4.97E+00-6.36E+00 1.83E-02 1.32E-02
1.11E-01-5.50E-01 1.69E-01 3.86E-01 6.36E+00-8.19E+00 1.27E-02 6.96E-03
5.50E-01-1.11E+00 2.16E-01 3.86E-01 8.19E+00-1.00E+01 7.34E-03 4.06E-03
1.11E+00-1.83E+00 1.47E-01 2.04E-01 1.00E+01-1.22E+01 0.00E-01 0.00E-01
1.83E+00-2.35E+00 1.05E-01 2.04E-01 1.22E+01-1.50E+01 0.00E-01 0.00E-01

* *

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 2 - ATR VERSION 4.
'
* *

GAMMA   SOURCE   INTERNAL FISSION
NORMALIZATION=1.000E+00 GAMMA   /KT, YIELD=1.000E+00 KT
 TOTAL OUTPUT=1.000E+00 GAMMA

                    SOURCE SPECTRUM
 ENERGY(MEV)   G   G/MEV   ENERGY(MEV)   G   G/MEV
2.00E-02-5.00E-02 3.08E-02 1.03E+00 1.33E+00-1.66E+00 6.18E-02 1.87E-01
5.00E-02-1.00E-01 1.36E-02 2.71E-01 1.66E+00-2.00E+00 3.94E-02 1.16E-01
1.00E-01-2.00E-01 8.16E-02 8.16E-01 2.00E+00-2.50E+00 3.76E-02 7.51E-02
2.00E-01-3.00E-01 6.87E-02 6.87E-01 2.50E+00-3.00E+00 2.23E-02 4.47E-02
3.00E-01-4.00E-01 8.68E-02 8.68E-01 3.00E+00-4.00E+00 2.12E-02 2.12E-02
4.00E-01-6.00E-01 1.77E-01 8.54E-01 4.00E+00-5.00E+00 7.48E-03 7.48E-03
6.00E-01-8.00E-01 1.40E-01 7.01E-01 5.00E+00-6.50E+00 3.23E-03 2.15E-03
8.00E-01-1.00E+00 1.00E-01 5.02E-01 6.50E+00-8.00E+00 6.79E-04 4.53E-04
1.00E+00-1.33E+00 1.07E-01 3.25E-01 8.00E+00-1.00E+01 1.58E-04 7.90E-05

* *

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 2 - ATR VERSION 4.

* *
  GROUND LEVEL   0.000KM,   0.000GM/CM**2,   0.000KFT,   0.000MILES
  HORIZ. RANGE RH= 0.100KM,   11.117GM/CM**2,   0.328KFT,   0.062MILES
 *SLANT RANGE   RS= 1.003KM, 117.080GM/CM**2,   3.291KFT,   0.623MILES
  TARGET ALT.   HT= 0.002KM,   0.245GM/CM**2,   0.007KFT,   0.001MILES
  SOURCE ALT.   HS= 1.000KM, 116.741GM/CM**2,   3.281KFT,   0.621MILES
 *SLANT ANGLE   AN= -84.278DEGREES (COS= 0.09970)
      *CALCULATED FROM OTHER COORDINATES

* *

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ATR SAMPLE PROBLEM 2 - OUTPUT (Cont'd.)

TOTAL   DOSE VS. HORIZ. RANGE   (RADS*CM**2)

DOSE 1=   HENDERSON TISSUE
DOSE 2=   CONCRETE
DOSE 3=   AIR
DOSE 4=   SILICON

HORIZ. RANGE	DOSE 1	DOSE 2	DOSE 3	DOSE 4
1.000E+02 M	2.91E-10	1.65E-10	1.39E-10	1.41E-10
2.000E+02 M	2.52E-10	1.41E-10	1.19E-10	1.19E-10
3.000E+02 M	2.08E-10	1.13E-10	9.60E-11	9.54E-11
4.000E+02 M	1.65E-10	8.82E-11	7.46E-11	7.36E-11
5.000E+02 M	1.26E-10	6.70E-11	5.66E-11	5.56E-11

* *
**EXECUTION COMPLETED

Sample Problem 3

This problem illustrates the X-ray related capabilities of the code. The source definition is a composite of two black body spectra, one with a temperature of 10 keV and the other of 20 keV. The weighting of each of the black body spectra is the same: 0.5. The total output is 0.4 KT. The geometry configuration consists of both the source and the target being on the ground and two slant ranges are used, one at 100 m and the other at 200 m. For each of the geometry configurations, the radiation summary is displayed on the output.

ATR SAMPLE PROBLEM 3 - INPUT

```
*TITLE SAMPLE PROBLEM 3 - ATR VERSION 4.
*X-SOURCE(1)
*BNDDY-E .4
*BNDDY-E 10 20
*BNDDY-X .5 .5
*HS 0
*HT 0
*RS 100 200
*PRINT/X/(1)
*EXC
```

ATR SAMPLE PROBLEM 3 - OUTPUT

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 3 - ATR VERSION 4.

* *

X-RAY   SOURCE   INTERNAL   BLACK   BODY
TOTAL ENERGY OUTPUT= 1.045E+28 KEV
 TOTAL OUTPUT=2.902E+25 X-RAY

                    SOURCE SPECTRUM
ENERGY(KEV)   X   X/KEV   ENERGY(KEV)   X   X/KEV
1.00E-01-1.00E+00 4.34E+23 4.82E+23 6.50E+01-7.50E+01 1.13E+25 1.13E+24
1.00E+00-1.00E+01 3.23E+25 3.59E+24 7.50E+01-9.00E+01 1.07E+25 7.15E+23
1.00E+01-1.50E+01 2.96E+25 5.91E+24 9.00E+01-1.05E+02 6.26E+24 4.17E+23
1.50E+01-2.00E+01 3.13E+25 6.26E+24 1.05E+02-1.20E+02 3.70E+24 2.46E+23
2.00E+01-2.50E+01 3.01E+25 6.01E+24 1.20E+02-1.40E+02 2.68E+24 1.34E+23
2.50E+01-3.00E+01 2.72E+25 5.44E+24 1.40E+02-1.60E+02 1.29E+24 6.46E+22
3.00E+01-3.50E+01 2.37E+25 4.73E+24 1.60E+02-1.90E+02 7.74E+23 2.58E+22
3.50E+01-4.50E+01 3.67E+25 3.67E+24 1.90E+02-2.20E+02 2.38E+23 7.93E+21
4.50E+01-5.50E+01 2.50E+25 2.50E+24 2.20E+02-2.60E+02 7.95E+22 1.99E+21
5.50E+01-6.50E+01 1.68E+25 1.68E+24 2.60E+02-3.00E+02 1.48E+22 3.69E+20

* *

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 3 - ATR VERSION 4.

* *
  GROUND LEVEL   0.000KM,   0.000GM/CM**2,   0.000KFT,   0.000MILES
 *HORIZ. RANGE RH=   0.100KM,   12.250GM/CM**2,   0.328KFT,   0.062MILES
  SLANT RANGE RS=   0.100KM,   12.250GM/CM**2,   0.328KFT,   0.062MILES
  TARGET ALT. HT=   0.000KM,   0.000GM/CM**2,   0.000KFT,   0.000MILES
  SOURCE ALT. HS=   0.000KM,   0.000GM/CM**2,   0.000KFT,   0.000MILES
 *SLANT ANGLE AN=   0.000DEGREES (COS= 1.00000)
         *CALCULATED FROM OTHER COORDINATES

* *

X-RAY   SUMMARY
                              UNCOLL.   TOTAL   BUILDUP   BACKWARD FORWARD
TISSUE DOSE   (RADS   ) 4.91E+05 1.18E+06 2.40E+00 7.34E+02 1.18E+06
SILICON DOSE   (RADS   ) 1.89E+06 5.15E+06 2.73E+00 5.52E+03 5.15E+06
NUMBER FLUENCE(X/CM**2) 1.03E+16 2.38E+16 2.31E+00 3.18E+15 2.03E+16
NUMBER CURRENT(X/CM**2) 1.02E+16 1.56E+16 1.53E+00 -1.62E+15 1.72E+16
ENERGY FLUENCE(X-CAL/CM**2) 2.69E+01 5.37E+01 2.00E+00 6.32E+00 4.74E+01
ENERGY CURRENT(X-CAL/CM**2) 2.66E+01 3.85E+01 1.45E+00 -2.90E+00 4.14E+01
EXT. FLX. WT. (   ) 0.00E-01 0.00E-01 0.00E-01 0.00E-01 0.00E-01
AVERAGE ENERGY(CAL)   2.61E-15 2.26E-15 8.66E-01 1.81E-15 2.53E-15

* *

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ATR SAMPLE PROBLEM 3 - OUTPUT (Cont'd.)

```
ATR PROBLEM NUMBER     1              SAMPLE PROBLEM 3 - ATR VERSION 4.

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
 GROUND LEVEL       0.000KM,    0.000GM/CM**2,    0.000KFT,    0.000MILES
*HORIZ. RANGE  RH=  0.200KM,   24.500GM/CM**2,   0.656KFT,    0.124MILES
 SLANT RANGE   RS=  0.200KM,   24.500GM/CM**2,   0.656KFT,    0.124MILES
 TARGET ALT.   HT=  0.000KM,    0.000GM/CM**2,    0.000KFT,    0.000MILES
 SOURCE ALT.   HS=  0.000KM,    0.000GM/CM**2,    0.000KFT,    0.000MILES
*SLANT ANGLE   AN=   0.000DEGREES (COS= 1.00000)

        *CALCULATED FROM OTHER COORDINATES

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

X-RAY                 SUMMARY
                                 UNCOLL.   TOTAL    BUILDUP  BACKWARD  FORWARD
TISSUE DOSE    (RADS     ) 1.23E+04 8.26E+04 6.70E+00 1.35E+02 8.25E+04
SILICON DOSE   (RADS     ) 3.66E+04 3.57E+05 9.75E+00 6.37E+02 3.56E+05
NUMBER FLUENCE(   X/CM**2 ) 2.80E+14 1.76E+15 6.28E+00 4.01E+14 1.36E+15
NUMBER CURRENT(   X/CM**2 ) 2.77E+14 8.22E+14 2.97E+00-1.90E+14 1.01E+15
ENERGY FLUENCE(  X-CAL/CM**2 ) 8.67E-01 3.97E+00 4.58E+00 7.64E-01 3.21E+00
ENERGY CURRENT(  X-CAL/CM**2 ) 8.58E-01 2.15E+00 2.50E+00-3.57E-01 2.50E+00
EXT. FLX. WT. (          ) 0.00E-01 0.00E-01 0.00E-01 0.00E-01 0.00E-01
AVERAGE ENERGY(CAL )      3.10E-15 2.26E-15 7.29E-01 1.90E-15 2.36E-15

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
**EXECUTION COMPLETED
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Sample Problem 4

This sample problem illustrates the use of the *CONSTRAINT command. The prompt gamma ray source spectrum uses is the standard fission source with a normalization value of 10^{24} gammas/KT and a yield of 20 KT. The neutron source is the built-in thermonuclear spectrum with a normalization of 6×10^{23} neutrons/KT and a weapon yield of 100 KT. One fixed component of the geometry is the source height at 1 km the other is the slant angle which varies from -10 degrees to 30 degrees in steps of 10 degrees. For each of the five geometry configurations the slant range is evaluated for which the response value is the same as specified by the *CONSTRAINT commands. The prompt gamma ray total fluence is constrained to have a value of 10^6, the neutron total fluence is constrained to have a value of 10^4 and the secondary gamma ray Henderson tissue dose constraint value is 0.1 rads.

```
*TITLE SAMPLE PROBLEM 4 - ATR VERSION 4.
*G-SOURCE(1)
*G-NORM 1+20
*G-YIELD 200
*N-SOURCE(2)
*N-NORM 6+23
*N-YIELD 100
*CHS,KM,1
*CAN -10(10)30
*CONSTRAINT/G/(RS 1 1+6)
*CONSTRAINT/N/(RS 1 1+4)
*CONSTRAINT/NG/(RS 5 1-1)
*EXC
```

ATR SAMPLE PROBLEM 4 - OUTPUT

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 4 - ATR VERSION 4.

* *

NEUTRON SOURCE   INTERNAL THERMONUCLEAR
NORMALIZATION=6.000E+23 NEUTRON /KT, YIELD=1.000E+02 KT
 TOTAL OUTPUT=6.000E+25 NEUTRON

                  SOURCE SPECTRUM
  ENERGY(MEV)   N   N/MEV   ENERGY(MEV)   N   N/MEV
 1.07E-05-2.90E-05 0.00E-01 0.00E-01 2.35E+00-2.46E+00 3.00E+23 2.73E+24
 2.90E-05-1.01E-04 1.20E+23 1.67E+27 2.46E+00-3.01E+00 1.14E+24 2.07E+24
 1.01E-04-5.83E-04 1.44E+24 2.99E+27 3.01E+00-4.07E+00 1.56E+24 1.47E+24
 5.83E-04-3.35E-03 7.32E+24 2.65E+27 4.07E+00-4.97E+00 1.02E+24 1.13E+24
 3.35E-03-1.11E-01 2.19E+25 2.03E+26 4.97E+00-6.36E+00 1.08E+24 7.77E+23
 1.11E-01-5.50E-01 6.12E+24 1.39E+25 6.36E+00-8.19E+00 8.82E+23 4.82E+23
 5.50E-01-1.11E+00 5.10E+24 9.11E+24 8.19E+00-1.00E+01 8.46E+23 4.67E+23
 1.11E+00-1.83E+00 3.72E+24 5.17E+24 1.00E+01-1.22E+01 1.50E+24 6.98E+23
 1.83E+00-2.35E+00 1.68E+24 3.23E+24 1.22E+01-1.50E+01 4.24E+24 1.51E+24

* *

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 4 - ATR VERSION 4.

* *

GAMMA   SOURCE   INTERNAL FISSION
NORMALIZATION=1.000E+24 GAMMA   /KT, YIELD=2.000E+02 KT
 TOTAL OUTPUT=2.000E+26 GAMMA

                  SOURCE SPECTRUM
  ENERGY(MEV)   G   G/MEV   ENERGY(MEV)   G   G/MEV
 2.00E-02-5.00E-02 6.17E+24 2.06E+26 1.33E+00-1.66E+00 1.24E+25 3.75E+25
 5.00E-02-1.00E-01 2.71E+24 5.42E+25 1.66E+00-2.00E+00 7.87E+24 2.31E+25
 1.00E-01-2.00E-01 1.63E+25 1.63E+26 2.00E+00-2.50E+00 7.51E+24 1.50E+25
 2.00E-01-3.00E-01 1.37E+25 1.37E+26 2.50E+00-3.00E+00 4.47E+24 8.93E+24
 3.00E-01-4.00E-01 1.74E+25 1.74E+26 3.00E+00-4.00E+00 4.23E+24 4.23E+24
 4.00E-01-6.00E-01 3.54E+25 1.77E+26 4.00E+00-5.00E+00 1.50E+24 1.50E+24
 6.00E-01-8.00E-01 2.80E+25 1.40E+26 5.00E+00-6.50E+00 6.46E+23 4.31E+23
 8.00E-01-1.00E+00 2.01E+25 1.00E+26 6.50E+00-8.00E+00 1.36E+23 9.05E+22
 1.00E+00-1.33E+00 2.15E+25 6.50E+25 8.00E+00-1.00E+01 3.16E+22 1.58E+22

* *

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 4 - ATR VERSION 4.

* *

NEUTRON   CONSTRAINT FOR SLANT RANGE AND NUMBER FLUENCE = 1.00E+04

*HORIZ. RANGE   SLANT RANGE   *TARGET ALT.   SOURCE ALT.   SLANT ANGLE
 5.2386E+03   5.3194E+03 M   7.6290E+01   1.0000E+03   -10.000 DEG
 5.5775E+03   5.5775E+03 M   1.0000E+03   1.0000E+03   0.000 DEG
 5.7408E+03   5.8293E+03 M   2.0123E+03   1.0000E+03   10.000 DEG
 5.7312E+03   6.0990E+03 M   3.0860E+03   1.0000E+03   20.000 DEG
 5.5519E+03   6.4108E+03 M   4.2054E+03   1.0000E+03   30.000 DEG
              *CALCULATED FROM OTHER COORDINATES

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ATR SAMPLE PROBLEM 4 - OUTPUT (Cont'd.)

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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ATR PROBLEM NUMBER      1            SAMPLE PROBLEM 4 - AIR VERSION 4.

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

GAMMA           CONSTRAINT FOR SLANT RANGE   AND NUMBER FLUENCE  = 1.00E+06

*HORIZ. RANGE    SLANT RANGE         *TARGET ALT.    SOURCE ALT.    SLANT ANGLE
  5.5668E+03      5.6525E+03 *        1.8431E+01     1.0000E+03     -10.000 DEG
  5.8883E+03      5.8883E+03 *        1.0000E+03     1.0000E+03       0.000 DEG
  6.0600E+03      6.1535E+03 *        2.0685E+03     1.0000E+03      10.000 DEG
  6.0641E+03      6.4532E+03 *        3.2071E+03     1.0000E+03      20.000 DEG
  5.8982E+03      6.8106E+03 *        4.4053E+03     1.0000E+03      30.000 DEG
            *CALCULATED FROM OTHER COORDINATES


* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ATR PROBLEM NUMBER      1            SAMPLE PROBLEM 4 - AIR VERSION 4.

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

NEUTRON GAMMA    CONSTRAINT FOR SLANT RANGE   AND HENDERSON TISSUE= 1.00E-01

*HORIZ. RANGE    SLANT RANGE         *TARGET ALT.    SOURCE ALT.    SLANT ANGLE
  4.4493E+03      4.5179E+03 *        2.1547E+02     1.0000E+03     -10.000 DEG
  4.6704E+03      4.6704E+03 *        1.0000E+03     1.0000E+03       0.000 DEG
  4.7602E+03      4.8336E+03 *        1.8393E+03     1.0000E+03      10.000 DEG
  4.7053E+03      5.0073E+03 *        2.7126E+03     1.0000E+03      20.000 DEG
  4.4927E+03      5.1878E+03 *        3.5939E+03     1.0000E+03      30.000 DEG
            *CALCULATED FROM OTHER COORDINATES


* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
**EXECUTION COMPLETED
```

<u>Sample Problem 5</u>

This problem illustrates the output of spectral information for neutrons and secondary gamma rays. The neutron source is the built-in 14 Mev spectrum with a normalization value of 2×10^{23} neutrons/KT and the yield is 10 KT. The source is located on the ground, the target is at 1 km and the slant range is 200 gm/cm^2. The output details the summary and spectral fluence values distributed over angle and over energy but not the full angle-energy distribution.

ATR SAMPLE PROBLEM 5 - INPUT

```
*TITLE SAMPLE PROBLEM 5 - ATR VERSION 1.
*N-SOURCE(S)
*N-PERM 2+25
*N-YIELD 10
*HS 0
*HT,KM,1
*RS,GM,200
*PRINT/N/(0 -1)
*PRINT/NG/(0 -1)
*EXC,
```

ATR SAMPLE PROBLEM 5 - OUTPUT

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 5 - ATR VERSION 4.

* *

NEUTRON SOURCE   INTERNAL 14MEV
NORMALIZATION=2.000E+23 NEUTRON /KT, YIELD=1.000E+01 KT
 TOTAL OUTPUT=2.000E+24 NEUTRON

                    SOURCE SPECTRUM
ENERGY(MEV)   N   N/MEV   ENERGY(MEV)   N   N/MEV
1.07E-05-2.90E-05 0.00E-01 0.00E-01 2.35E+00-2.46E+00 0.00E-01 0.00E-01
2.90E-05-1.01E-04 0.00E-01 0.00E-01 2.46E+00-3.01E+00 0.00E-01 0.00E-01
1.01E-04-5.83E-04 0.00E-01 0.00E-01 3.01E+00-4.07E+00 0.00E-01 0.00E-01
5.83E-04-3.35E-03 0.00E-01 0.00E-01 4.07E+00-4.97E+00 0.00E-01 0.00E-01
3.35E-03-1.11E-01 0.00E-01 0.00E-01 4.97E+00-6.36E+00 0.00E-01 0.00E-01
1.11E-01-5.50E-01 0.00E-01 0.00E-01 6.36E+00-8.19E+00 0.00E-01 0.00E-01
5.50E-01-1.11E+00 0.00E-01 0.00E-01 8.19E+00-1.00E+01 0.00E-01 0.00E-01
1.11E+00-1.83E+00 0.00E-01 0.00E-01 1.00E+01-1.22E+01 0.00E-01 0.00E-01
1.83E+00-2.35E+00 0.00E-01 0.00E-01 1.22E+01-1.50E+01 2.00E+24 7.14E+23

* *

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 5 - AIR VERSION 4.

* *
 GROUND LEVEL   0.000KM,   0.000GM/CM**2,   0.000KFT,   0.000MILES
*HORIZ. RANGE RH=   1.391KM, 170.400GM/CM**2,   4.564KFT,   0.864MILES
 SLANT RANGE   RS=   1.713KM, 200.000GM/CM**2,   5.621KFT,   1.065MILES
 TARGET ALT.   HT=   1.000KM, 116.741GM/CM**2,   3.281KFT,   0.621MILES
 SOURCE ALT.   HS=   0.000KM,   0.000GM/CM**2,   0.000KFT,   0.000MILES
*SLANT ANGLE   AN= 35.712DEGREES (COS= 0.81197)
        *CALCULATED FROM OTHER COORDINATES

* *

NEUTRON   SUMMARY
                                UNCOLL.   TOTAL   BUILDUP   BACKWARD FORWARD
TISSUE DOSE   (RADSACM**2   ) 1.93E+10 5.17E+13 2.69E+03 1.57E+13 3.60E+13
SILICON DOSE (RADSACM**2   ) 3.03E+09 1.55E+12 5.11E+02 2.48E+11 1.30E+12
NUMBER FLUENCE(N   ) 3.53E+18 6.44E+22 1.83E+04 2.74E+22 3.70E+22
NUMBER CURRENT(N   ) 3.49E+18 6.83E+21 1.96E+03-1.33E+22 2.01E+22
ENERGY FLUENCE(N-MEV   ) 4.80E+19 4.04E+22 8.43E+02 8.99E+21 3.14E+22
ENERGY CURRENT(N-MEV   ) 4.74E+19 1.85E+22 3.89E+02-1.22E+22 2.27E+22
EXT. FLX. WT. (   ) 0.00E-01 0.00E-01 0.00E-01 0.00E-01 0.00E-01
AVERAGE ENERGY(MEV)   1.36E+01 6.28E-01 4.62E-02 3.28E-01 8.51E-01

* *

ATR SAMPLE PROBLEM 5 - OUTPUT (Cont'd)

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 5 - ATR VERSION 4.

* *

NEUTRON   NUMBER FLUENCE

DISTRIBUTION OVER ANGLE

ANG	DEGREES	COSINE	SUM OVER ENERGY	CUMULATIVE SUM
		(N/STER	) (	N)
1	180.0 - 166.6	-1.0000 - -0.9728	3.950E+21	6.739E+20
2	166.6 - 155.6	-0.9728 - -0.9106	3.984E+21	2.232E+21
3	155.6 - 144.6	-0.9106 - -0.8154	4.045E+21	4.651E+21
4	144.6 - 133.7	-0.8154 - -0.6908	4.133E+21	7.867E+21
5	133.7 - 122.8	-0.6908 - -0.5412	4.246E+21	1.186E+22
6	122.8 - 111.8	-0.5412 - -0.3720	4.385E+21	1.654E+22
7	111.8 - 100.9	-0.3720 - -0.1894	4.547E+21	2.176E+22
8	100.9 - 90.0	-0.1894 - 0.0000	4.730E+21	2.739E+22
9	90.0 - 79.1	0.0000 - 0.1894	4.930E+21	3.326E+22
10	79.1 - 68.2	0.1894 - 0.3720	5.142E+21	3.915E+22
11	68.2 - 57.2	0.3720 - 0.5412	5.455E+21	4.495E+22
12	57.2 - 46.3	0.5412 - 0.6908	5.845E+21	5.045E+22
13	46.3 - 35.4	0.6908 - 0.8154	6.377E+21	5.548E+22
14	35.4 - 24.4	0.8154 - 0.9106	7.018E+21	5.968E+22
15	24.4 - 13.4	0.9106 - 0.9728	7.808E+21	6.274E+22
16	13.4 - 0.0	0.9728 - 1.0000	9.013E+21	6.427E+22

* *

DISTRIBUTION OVER ENERGY

	ENERGY(MEV)	SUM OVER ANGLE	CUMULATIVE SUM
		(N/MEV	) (N)
1	0.00E-01-4.14E-07	4.721E+27	1.955E+21
2	4.14E-07-1.12E-06	3.055E+27	4.112E+21
3	1.12E-06-3.06E-06	1.329E+27	6.691E+21
4	3.06E-06-1.07E-05	4.710E+26	1.029E+22
5	1.07E-05-2.90E-05	1.651E+26	1.331E+22
6	2.90E-05-1.01E-04	5.369E+25	1.718E+22
7	1.01E-04-5.83E-04	1.162E+25	2.278E+22
8	5.83E-04-3.35E-03	2.119E+24	2.864E+22
9	3.35E-03-1.11E-01	1.331E+23	4.297E+22
10	1.11E-01-5.50E-01	1.937E+22	5.147E+22
11	5.50E-01-1.11E+00	8.424E+21	5.619E+22
12	1.11E+00-1.83E+00	3.335E+21	5.859E+22
13	1.83E+00-2.35E+00	2.241E+21	5.976E+22
14	2.35E+00-2.46E+00	2.260E+21	6.001E+22
15	2.46E+00-3.01E+00	1.272E+21	6.071E+22
16	3.01E+00-4.07E+00	6.570E+20	6.138E+22
17	4.07E+00-4.97E+00	8.343E+20	6.215E+22
18	4.97E+00-6.36E+00	6.242E+20	6.300E+22
19	6.36E+00-8.19E+00	2.968E+20	6.354E+22
20	8.19E+00-1.00E+01	1.545E+20	6.382E+22
21	1.00E+01-1.22E+01	9.068E+19	6.402E+22
22	1.22E+01-1.50E+01	1.310E+20	6.439E+22

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NEUTRON GAMMA   SUMMARY

	UNCOLL.	TOTAL	BUILDUP	BACKWARD	FORWARD
TISSUE DOSE (RADS*CM**2)	0.00E-01	3.76E+13	0.00E-01	2.36E+12	3.53E+13
SILICON DOSE (RADS*CM**2)	0.00E-01	4.12E+13	0.00E-01	3.77E+12	3.74E+13
NUMBER FLUENCE(G)	0.00E-01	9.89E+22	0.00E-01	2.89E+22	7.00E+22
NUMBER CURRENT(G)	0.00E-01	3.29E+22	0.00E-01	-1.35E+22	4.63E+22
ENERGY FLUENCE(G-MEV)	0.00E-01	1.05E+23	0.00E-01	4.82E+21	1.01E+23
ENERGY CURRENT(G-MEV)	0.00E-01	8.91E+22	0.00E-01	-2.13E+21	9.12E+22
EXT. FLX. WT. ( )	0.00E-01	0.00E-01	0.00E-01	0.00E-01	0.00E-01
AVERAGE ENERGY(MEV)	0.00E-01	1.07E+00	0.00E-01	1.67E-01	1.44E+00

* *

ATR PROBLEM NUMBER   1   SAMPLE PROBLEM 5 - ATR VERSION 4.

* *

NEUTRON GAMMA   NUMBER FLUENCE

DISTRIBUTION OVER ANGLE

ANG	DEGREES	COSINE	SUM OVER ENERGY (G/STER)	CUMULATIVE SUM (G)
1	180.0 - 166.6	-1.0000 - -0.9728	3.782E+21	6.452E+20
2	166.6 - 155.6	-0.9728 - -0.9106	3.841E+21	2.144E+21
3	155.6 - 144.6	-0.9106 - -0.8154	3.948E+21	4.508E+21
4	144.6 - 133.7	-0.8154 - -0.6908	4.106E+21	7.124E+21
5	133.7 - 122.8	-0.6908 - -0.5412	4.319E+21	1.178E+22
6	122.8 - 111.8	-0.5412 - -0.3720	4.587E+21	1.666E+22
7	111.8 - 100.9	-0.3720 - -0.1894	4.921E+21	2.230E+22
8	100.9 - 90.0	-0.1894 - 0.0000	5.331E+21	2.865E+22
9	90.0 - 79.1	0.0000 - 0.1894	5.834E+21	3.559E+22
10	79.1 - 68.2	0.1894 - 0.3720	6.461E+21	4.301E+22
11	68.2 - 57.2	0.3720 - 0.5412	7.435E+21	5.091E+22
12	57.2 - 46.3	0.5412 - 0.6908	8.971E+21	5.936E+22
13	46.3 - 35.4	0.6908 - 0.8154	1.121E+22	6.812E+22
14	35.4 - 24.4	0.8154 - 0.9106	1.531E+22	7.727E+22
15	24.4 - 13.4	0.9106 - 0.9728	2.493E+22	8.705E+22
16	13.4 - 0.0	0.9728 - 1.0000	6.520E+22	9.815E+22

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                         DISTRIBUTION OVER ENERGY
    ENERGY(MEV )         SUM OVER ANGLE   CUMULATIVE SUM
                    (    G/MEV          ) (    G              )
  1  2.00E-02-5.00F-02      1.740F+23        5.220F+21
  2  5.00E-02-1.00F-01      6.108E+23        3.576F+22
  3  1.00E-01-2.00F-01      2.055F+23        5.631F+22
  4  2.00E-01-3.00F-01      6.623E+22        6.293F+22
  5  3.00F-01-4.00F-01      3.671F+22        6.660F+22
  6  4.00F-01-6.00F-01      2.506F+22        7.161F+22
  7  6.00F-01-8.00F-01      1.221F+22        7.405F+22
  8  8.00F-01-1.00F+00      8.443E+21        7.584F+22
  9  1.00F+00-1.33F+00      6.616F+21        7.803F+22
 10  1.33E+00-1.66F+00      5.889E+21        7.997F+22
 11  1.66F+00-2.00F+00      4.467F+21        8.149F+22
 12  2.00E+00-2.50F+00      4.562F+21        8.577F+22
 13  2.50E+00-3.00F+00      3.155F+21        8.555F+22
 14  3.00E+00-4.00F+00      3.123F+21        8.847F+22
 15  4.00F+00-5.00F+00      2.627F+21        9.110F+22
 16  5.00F+00-6.50F+00      2.952F+21        9.553F+22
 17  6.50F+00-8.00F+00      1.890F+21        9.836F+22
 18  8.00F+00-1.00F+01      2.545F+20        9.847F+22
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**EXECUTION COMPLETED
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